KEMP

The magnetic properties of certain rare earths

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THE MAGNETIC PROPERTIES OF CERTAIN RARE EARTHS

BY

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A. B. University of Illinois, 1906

THESIS

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May 26, 1910

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JACOB GARRETT KEMP

ENTITLED THE MAGNETIC PROPERTIES OF CERTAIN RARE EARTHS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ARTS in PHYSICS

Wm F. Schulz.
In Charge of Major Work

A. P. Carman
Head of Department

Recommendation concurred in:

Committee
on
Final Examination

Introduction.

The rare earths are obtained from minerals the majority of which are very rare and occur only in isolated parts of the earth's crust, in Germany, in Scandinavia, and in North and South America. Cerite, Orthite(Allanite), Monazite, and Aschynite are the names of the Minerals from which the Cerium group of the rare earths are obtained. This group comprises the elements Cerium, Lanthanum, Praseodymium, Neodymium, Samarium, Gadolinium, and Europium. The other group which is known as the Yttrium group comprises the elements Yttrium, Scandium, Terbium, Dysprosium, Holmium, Erbium, Thulium, and Ytterbium. This group is obtained from Gadolite(Ytterbite), Yttrialith, Xenotim, Fergusonite, Yttrotantalite, Samarskite, Polykras, and Euxenite.
Although these minerals are placed in one or the other of the Cerium or Yttrium groups it does not signify that some of them do not yield rare earths of the other group.

A table of the rare earths arranged according to their atomic weights is given below.

	Element	Atomic Weight.
x	Scandium,Sc.	44.1
x	Yttrium,Y.	88.9
x	Lanthanum,La.	139.0
x	Cerium,Ce.	140.2
o	Praseodymium,Pr.	140.9
o	Neodymium,Nd.	143.9
o	Samarium,Sa.	150.4
o	Europium,Eu.	151.9
x	Gadolinium,Gd.	157.2
x	Terbium,Tb.	159.2
o	Dysprosium,Dy.	162.5
o	Holmium,Ho.	has not been isolated.
o	Erbium,Er.	166.0
o	Thulium,Tu.	171.0
x	Ytterbium,Yb.	173.1

The elements underscored belong to the Cerium group.

The elements not underscored belong to the Yttrium group.

The elements marked x have emission spectra only.

The elements marked o have both spectra.

Reference:- Abegg's Handbuch der Anorganischen Chemie,111.

Chemical Properties.

The chemical properties of the rare earths are similar to those of Aluminium.The free metals are more readily oxidisable the greater their combining weight,and in the same sense the bases become stronger.But on account of the close agreement of their chemical properties it is an exceedingly difficult task to separate these elements from one another.Nor are there any methods of separation such as are employed for other analytical purposes.The only method applicable is the partial separation on the basis of slight differences in solubility,of chemical equilibrium,and of decomposability,by the repeated performance of which the object is more or less obtained.Years ago the number of the rare earth~~s~~ elements was comparatively small. They have increased however,owing to the fact that almost every investigation which has been carried out with much thoroughness has shown that some one of the substances hitherto regarded as simple is a mixture.It is by no means probable that these separations have already reached a definite conclusion.For example,Didymium was supposed to be an element but it was later separated into Praseodymium and Neodymium;Ytterbium separated into Aldebaranium and Cassiopeium; and,even now at this writing the separation of Erbium into two or more substances is expected by some chemists.

The method of separation is by fractional crystallizations which is a long tedious task.Urbain spent ten years getting pure Europium after 6000 crystallizations.These separations are produced, for example,by partial precipitation of the salt solution with insufficient ammonia,and this process repeated until the combining

weight of the fractions obtained no longer changes om further separation.

The most reliable method of examination of the solution after precipitation is by means of the spectrum which brings out some remarkable results. Many of these elements give a very complicated spectrum on allowing the electric spark to pass between carbon points moistened with solutions of the salts of the rare earths. Since under given conditions, each element possesses a perfectly definite spectrum, it can be seen whether or not the spectrum changes by partial separations.

Physical Properties.

Some of these elements have absorption spectra which are readily obtained by allowing white light to pass through solutions of the salts and then examining it with the spectroscope. Dark bands are then seen in definite positions which are characteristic of the elements. Some of the rare earths do not have absorption spectra but they do have emission spectra. Cerium, Lanthanum, Gadolinium, Terbium, Yttrium, Ytterbium, and Scandium have only the emission spectra, while Praseodymium, Neodymium, Samarium, Europium, Dysprosium, Holmium, Erbium, and Thulium have both absorption and emission spectra.

The oxides of some when heated to incandescence, do not emit continuous light, as solids usually do, but the emitted light is found by the spectroscope to consist of isolated bands similar to the light of incandescent gases but much broader.

Another kind of optical phenomenon, the importance of which for the characterization of the elements has not yet been fully demonstrated, consists in the phosphoresence produced by the cathode rays. When electrical discharges of high potential are allowed to

pass through a high vacuum,rays of a special kind are emitted from the cathode,which are propagated in straight lines,and which render luminous many substances with which they come in contact.The light thus produced differs also for different substances.(Ostwald- The Principles of Inorganic Chemistry).

Cerium is used in a technical way by its addition to thoria in the manufacture of incandescent mantles.

It might be mentioned too,that Erbium is radio-active while this property has not been detected in any other of the rare earths.

Although much work has been done on the chemical properties of the rare earths,yet comparatively little has been done on the investigation of the physical properties.Of the physical properties the analysis of the spectra of these elements has been the most productive field for investigation and there is much literature on this subject.The magnetic properties however,have not been investigated extensively due to the fact that it does not prove of any aid as yet in discerning the element in a solutuion or a compound,which fact was the primary incentive for the work done on their spectra.

It seems very probable however,that they may be discerned one from another by their magnetic properties which are different in that there is a definite variation shown by the elements thus far investigated.The literature on the magnetic properties of the rare earths is very limited,no doubt due to the difficulty in getting pure rare earths or compounds which contain only one of these elements.

Reference:- H.Kayser,Handbuch der Spectroscopie.

Literature on Magnetic Properties.

The susceptibility of Praseodymium was determined by du Bois and Liebknecht,(Landolt Boernstein tables 1905.)

Stefan Meyer,Sitzber.Wien Akad.page 995,1908,determined the molecular susceptibility of salts of Cerium,Praseodymium,Neodymium, Samarium,Gadolinium,Holmium,Erbium,and Ytterbium separated into Aldebaranium and Cassiopeium. The field strength used was 10000 gauses and the method "Iron free balance",which was not described. This balance is very likely the Curie torsion magnetic balance. Meyer shows the relation between the number of spectrum lines and the magnetism number or susceptibility (molecular).He concludes that the strongly magnetic of these elements have many spectrum lines while the diamagnetic elements have few spectrum lines.

This work was severely criticised by B. Urbain and G. Jantsch on the ground that the substances used were not pure.

G. Urbain,(Comp.Rend.Vol.146,page 922,1908.) shows that Dysprosium has comparatively strong magnetic properties.

The best paper on the subject is by B. Urbain and G. Jantsch (Comp.Bend.Vol.147,page 1286,1908.) "Upon the Magnetism of Rare Earths".

Oxides of the form X_2 O_3 were investigated by means of the apparatus of Curie and Cheneveau which is neither described nor is there a reference given from which a description could be obtained. The authors of this paper claim that the Cerium group,when arranged in the order of their atomic weights,shows a maximum magnetism in the series,while the Yttrium group also shows a maximum. Lanthanum the first of the Cerium group is diamagnetic.

Praseodymium is paramagnetic but is less so than Neodymium, which is about five times as magnetic as Samarium. In the same way Europium is much less magnetic than Gadolinium. The magnetism continues to increase with members of the Yttrium group with Terbium much more magnetic than Gadolinium, and Dysprosium much more than Terbium. The next in order is Holmium about which little can be said, (since it has not been isolated), except that its magnetism is high. In this series the maximum appears in the neighborhood of Dysprosium, Holmium, and Erbium with a decrease from Holmium to Erbium or from Erbium to Thulium through the two components of Ytterbium, which are called Neoytterbium and Lutécium. (Stefan Meyer calls the last two Aldebaranium and Cassiopeium respectively).

The following table of data is given.

Element	Atomic weight.	X 10^6
Neodymium	144.3	33.5
Samarium	150.4	6.5
Europium	152.0	33.5
Gadolinium	157.3	161.0
Terbium	159.2	237
Dysprosium	162.2	290

X 10^6 is the coefficient of magnetization, the value X $10^6 = 39.7$ for sulfate of Cobalt, given by M. Meslin, being taken as a standard. It is not explained how this was used but evidently sulfate of Cobalt was used to calibrate the apparatus with which the measurements were made.

The literature on the subject of magnetic properties shows the following:- A study of relation between number of spectrum lines and magnetic properties shows that a strongly magnetic rare earth has a large

number of spectrum lines, and a diamagnetic rare earth has a small number of spectrum lines. In this respect the salts of Cerium, Praseodymium, Neodymium, Samarium, Gadolinium, Holmium, Erbium, and Yttrium separated into Aldebaranium and Cassiopeium were investigated to substantiate these conclusions.

The rare earths when arranged according to their atomic weight show two maximum values of magnetization in the group. All of the necessary values to substantiate these conclusion were not given.

There is no attempt to show any variation with the temperature changes.

Without any definite statement it seems that it is assumed that the magnetic properties vary directly with the magnetic field strength.

Only mean values for the molecular susceptibility are given.

Purpose.

In 1907, while pursuing an investigation of spectrum phenomena of certain salts of the rare earths in a strong magnetic field, Dr. Wm. F. Schulz discovered that Erbium and Neodymium oxides showed very decided magnetic properties.

At the suggestion of DR. Schulz it was thought worth while to investigate the magnetic properties of as many of the compounds of the rare earths as could readily be obtained.

The object of this investigation is thus:-

(a) to show the variation of the magnetic properties with the

change in the magnetic field strength;

(b) to compare the values thus obtained for the different substances;

(c) to show whether or not temperature changes have any affect on the magnetic properties.

Substances Investigated.

Only five compounds of the rare earths were available, namely :- the oxides of Erbium,Yttrium,Neodymium,Praseodymium, Terbium,and the sulfate of Neodymium.

Four different specimens of Yttrium oxide,one each of Terbium oxide,Erbium oxide,Praseodymium oxide,Neodymium oxide,and Neodymium sulfate were investigated,and tables and curves are given as the results of this investigation.

I wish to acknowledge my indebtedness to Dr.C.W.Balke,and to Mr.J.E.Egan of the Chemistry Department for some of the rare earths used in this investigation.

Theory of Method.

If a magnetic body be suspended, by means of an elastic suspension, in a magnetic field such that the longer axis of the body be perpendicular to the direction of the field, it will be deflected so that its axis makes some angle with its former position.

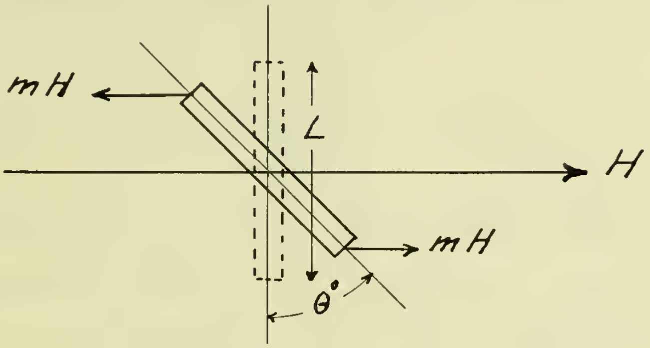


Fig. 1.

Suppose figure 1, to represent the conditions. Let H, be the field strength, m, the magnetic pole strength due to magnetic induction, L the length of specimen, θ°, the angle through which the specimen has been deflected.

Then the magnetic torque acting on the body is $mHL \cos \theta$. For a position of equilibrium the resisting torque exerted by the elastic suspension is

$$\frac{\pi r^4 n}{2b \times 57.29}\,\theta^\circ$$

in which r is the radius, n is the coefficient of rigidity, b is the length, and θ° is the angle of torsion of the suspension.

If the suspension is twisted through some angle say Φ° in order to produce a torque in the suspension equal to the magnetic torque, then the total angle of torsion is $\Phi^\circ + \theta^\circ$ which will be denoted

by B°.

By equating the magnetic and suspension torques we have

$$m\ H\ L\ \mathrm{Cos}\ \theta = \frac{\pi r^4\ n}{2\ b \times 57.29}\ B^\circ$$ from which the

magnetic moment is $$m\ L = \frac{\pi r^4\ n}{114.58\ b}\ \frac{B^\circ}{H\ \mathrm{Cos}\ \theta}.$$

Since the magnetic intensity is equal to the magnetic moment per unit volume,the magnetic intensity is

$$A = \frac{m\ L}{V} = \frac{\pi\ r^4\ n}{114.58\ b}\ \frac{B^\circ}{H\ \mathrm{Cos}\ \theta}.$$

In the above equation it is seen that if the same suspension be used in all the work then $\pi\ r^4\ n\ /\ 114.58\ b$ is a constant with B,θ, H, and V as the variables.It is seen that B, θ, and H vary for each particular value of magnetic field strength while the volume V varies only for different specimens.

The equation for each specimen may be written

$$A = \frac{\pi\ r^4\ n}{114.58\ b\ V}\ \frac{B^\circ}{H\ \mathrm{Cos}\ \theta} = K\ \frac{B^\circ}{H\ \mathrm{Cos}\ \theta}$$

in which K may be determined and the computations thus simplified. Thus it is seen that the constant K will be different for different specimens on account of their volumnes not being the same.

Description of Apparatus.

A du Bois electromagnet was used to produce the magnetic fields with maximum value of 16000 lines per square centimeter in an air-gap of 2.8 cms.The poles of the magnet were of soft iron chamfered down to a circular face about 2.5 cm.in diameter.

The suspension was of number 36 B & S gauge phosphorbronze wire, diameter 0.0127 cm.,length 48.2 cm.,and coefficient of rigidity 4.0×10^{11} . This was fastened to an ordinary,graduated torsion head.

Figure 2 gives a diagram of an elevation of the magnet,torsion head,and suspended system.The suspended system is a strip of glass 1.5 cm.wide,0.3 cm.thick,and 25 cms. long.In the upper end is a hole 0.65 cm.in diameter in which the cylindrical specimens were placed,and the lower end was immersed in a beaker of heavy cylinder oil to produce damping.The mirror was placed just above the beaker of oil in order to get it as far as possible from the influence of the magnetic field.At first the mirror was placed just above the specimen but a torque was produced when strong fields were used. This was due to the fact that silver is a diamagnetic substance and the mirror would tend to place its plane perpendicular to the direction of the magnetic field.

Figure 3 gives a diagram of the plan of the arrangement from which the method of getting the angles of deflection may be explained.

In this arrangement the ordinary telescope and scale is used and in addition an auxiliary telescope the purpose of which will be explained later.

It is seen that much labor in the determination of the angle θ may be eliminated if the angle θ is always kept equal to zero. This may be done by torsion of the suspension the torque of which must be,in all positions of the specimen,equal to the magnetic torque.But this zero position of equilibrium was found to be exceedingly difficult to maintain.When this position was slowly

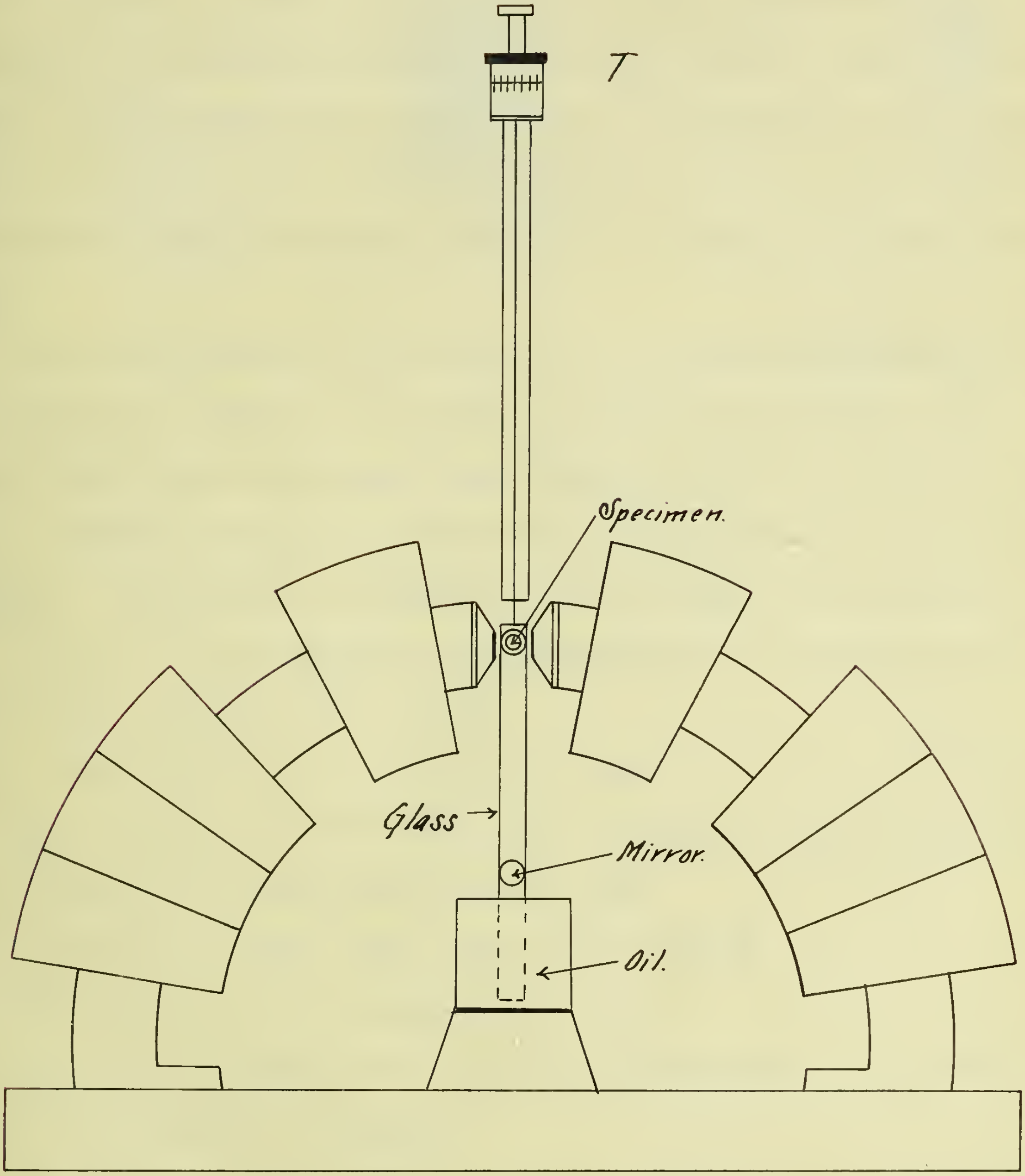


Fig. 2.

reached by the specimen it would generally reverse its polarity suddenly and a torque opposite to that of the first exerted by the field. Thus it was found that the larger angle θ was made the more easily it was to produce equilibrium. For this reason the auxiliary telescope T was used, the deflections being off the scale for telescope O at the center. The deflections in the direction of telescope T could always be read since they would always be on the scale for this arrangement. This avoided the necessity of using an extremely long scale.

The determination of the angle θ is as follows. In figure 3 for zero field, reading t is taken at telescope T, reading O, at telescope O. Angle a, is ~~the~~ equal $\tan^{-1}(t-O)/s$, where s is the perpendicular scale distance from mirror. When a deflection is produced reading t' is taken in telescope T and the angle b is ~~the~~ equal to $\tan^{-1}(t'-O)/s$. And from the diagram it is seen that angle

$h = 2b + 2\theta$, also $h = b + a$; then

$$2b + 2\theta = b + a \text{ , or } \theta = (a - b)/2 \text{ .}$$

When reading t' is to the right of reading O and b is greater than a then it is seen from figure 4 that

$\theta = a - h/2$ or $h = 2a - 2\theta$, and $h = a - b$; then

$2a - 2\theta = a - b$, or $\theta = (a+b)/2$.

The angle a is a constant for one set of readings while angle b changes for different readings.

The specimens were made by making a paste of the rare earths with a few drops of the bromide solution of each substance used. This was pressed into small glass tubes about 2.5 cm. long with a bore about 0.38 cm. in diameter. These specimens were kept in the glass tubes so that they could be readily and carefully handled.

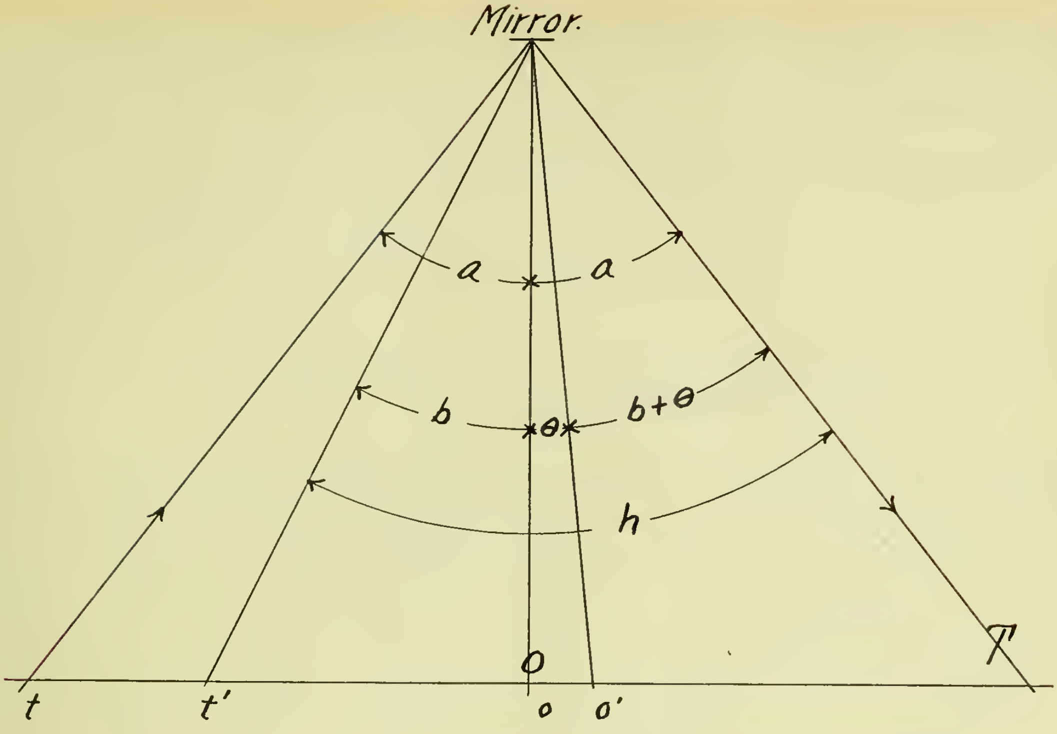


Fig. 3.

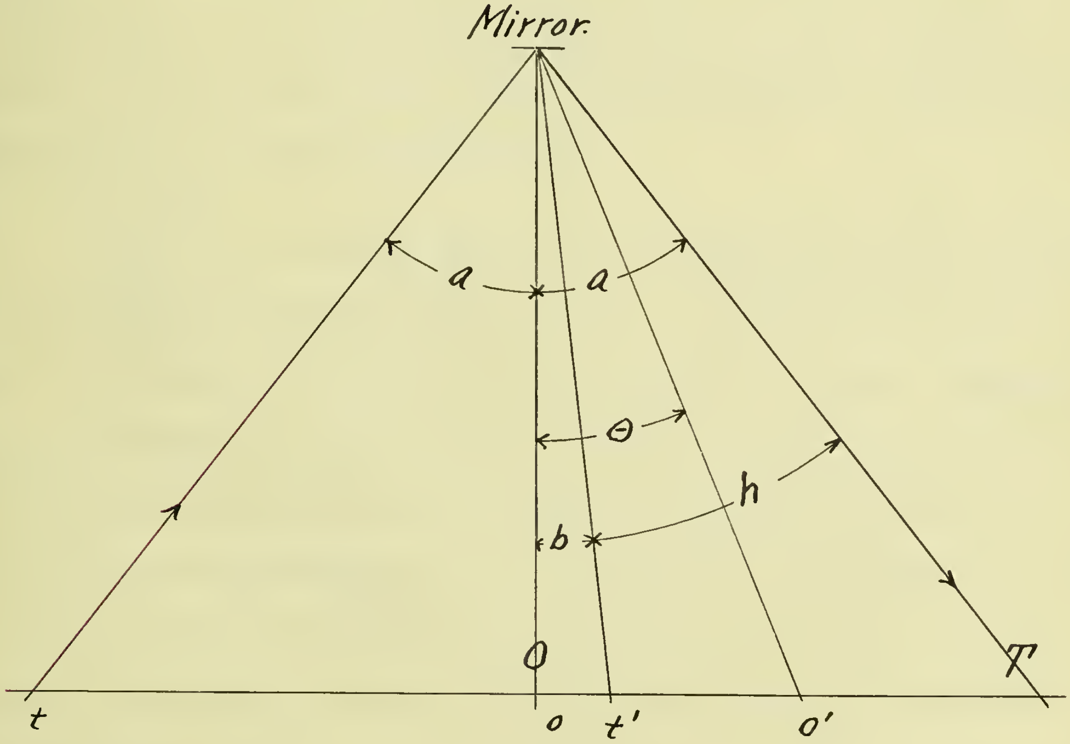


Fig. 4.

When a series of observations was to be taken it was found very convenient to slip the specimen into place in the suspended system.

The length,diameter,volume,and density of each specimen is recorded om each data sheet.

Calibration of the Magnetic Field.

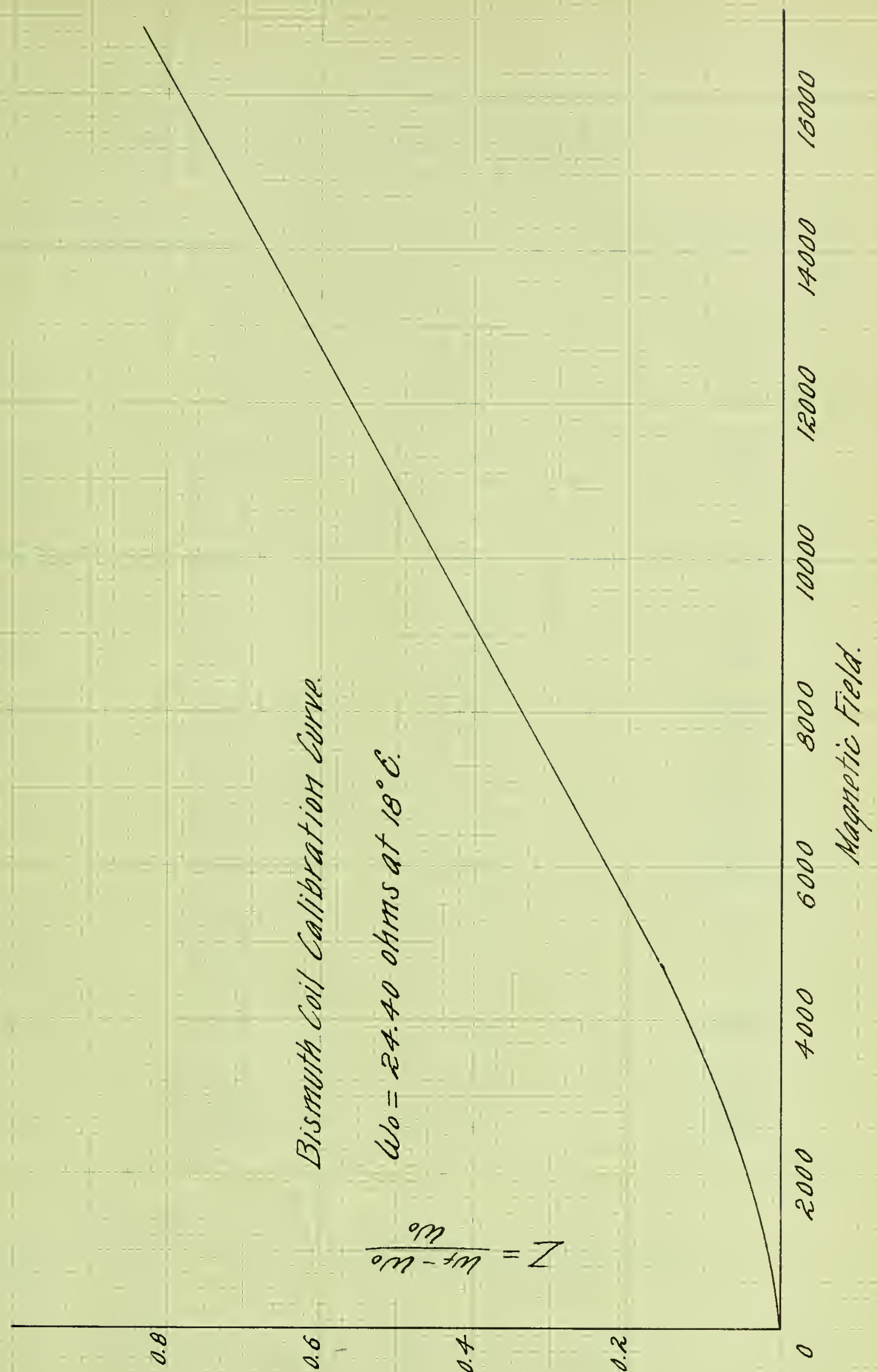
The field strength H,was determined by means of a Hartmann and Braun spiral #558 of Bismuth.The resistance of bismuth increases with the strength of magnetic field in which it is placed This gives a very easy means for determining magnetic field strength

The spiral was placed with its plane perpendicular to the direction of the magnetic field and its resistance W_o measured in zero field strength.Then readings were made of the current flowing in electromagnet coil,and the resistance of bismuth spiral W_f for different current strengths. From the calibration curve for the spiral,given on next page,which has

$$Z = \frac{W_f - W_o}{W_o}$$

for ordinates and H in lines per square centimeter for abscissae,the corresponding values of H may be taken.For each value of H there is a corresponding value of current I,and,from these a calibration curve for the field strength against the current strength which produces it ,may be plotted.The curve is shown below with current strengths I,for ordinates and magnetic field strengths H,for abscissae.From this curve the values of field strength H are read for the corresponding values of current I for each reading.

On account of the temperature variations of the resistance of



Bismuth Coil Calibration Curve.

Calibration of Magnetic Field.

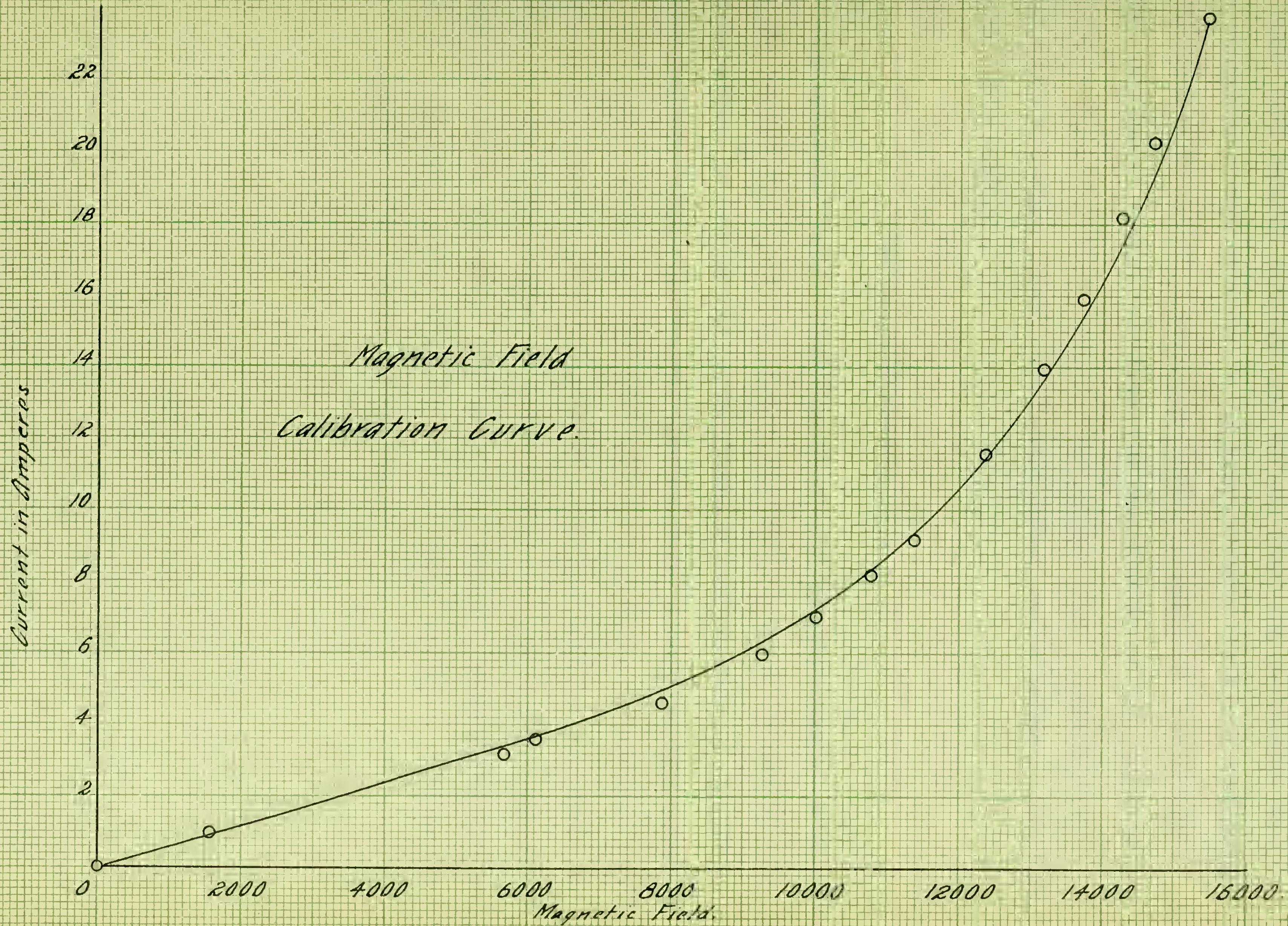
April 25th. 1910. Temp. 17°.9 C.

W_f	Z	I	H
24.4	0	0	0
25.1	0.030	.90	1550
29.4	0.210	3.10	5650
30.10	0.235	3.40	6100
32.5	0.333	4.54	7850
34.3	0.405	5.80	9225
35.3	0.448	6.84	10000
36.3	0.490	8.10	10750
37.1	0.520	9.20	11325
38.4	0.575	11.48	12325
39.5	0.620	13.88	13150
40.3	0.650	15.80	13700
41.0	0.680	18.08	14250
41.6	0.705	20.24	14700
42.5	0.742	23.70	15450

$$Z = \frac{W_f - W_0}{W_0}$$

W_0 = 24.4 ohms at 18° C.

H in number of lines per cm.^{2} I in amperes.


Magnetic Field
Calibration Curve.
Current in Amperes
22
20
18
16
14
12
10
8
6
4
2
0
2000
4000
6000
8000
10000
12000
14000
16000
Magnetic Field.

the Bismuth Spiral a correction must be made .But the temperature was kept very nearly constant,at 18°,so that the necessity for this correction was avoided.It is said,however,that the variation in the measurements of a magnetic field by means of the bismuth spiral are quite large,but ~~from~~ the smoothness of the calibration curve obtained ~~it~~ shows that no very large errors were present. But a constant error might be present which would cause a shifting of the whole curve.

Data and Calculations.

The following pages show the data and calculations of θ°,B°, I in amperes,H in lines per square centimeter,A the intensity of magnetization in C.G.S. units,temperature,length,area of cross-section,volume,mass,density,and the constant K used in the equation. For each set of readings for each specimen a curve is plotted with A,intensity of magnetization as ordinates,and H,field strength as abscissae.The total number of these curves is twenty-four for rare earths.One curve was taken for glass and one for phosphorbronze in order to show that the effect of the presence of these substances in the magnetic field could be neglected.

Erbium Oxide

April 20th. 1910. NO. 1. Temp. 22°.5 C
7:40 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
14° 9'	.9697	14.2	.88	1600	7.13
19° 6'	.9449	187	3.10	5650	27,3
18°54'	.9461	226	3.40	6100	30.5
18°54'	.9461	379	4.50	7850	39.8
18°48'	.9466	532	5.60	8900	49.3
18°35'	.9479	619	6.80	10000	50.8
18°48'	.9466	719	7.90	10450	56.50
18°48'	.9466	805	8.90	11250	59.0
18°28'	.9484	946	11.00	12250	63.5
18°28'	.9484	1031	13,20	13100	64.7
18°35'	.9479	1139	14.90	13650	68.7
18°29'	.9484	1246	17.00	14200	72.1
18°29'	.9484	1318	19.00	14700	73.7
16°34'	.9585	1451	22.20	15250	77.5

Mass of specimen 0.859 gr. Length 2.48 cm. Diam.0.3885 cm.

Volume " " 0.2938 cm.^{3} Area cross section 0.1185 cm.^{2}

Density 2.93 Constant k= 0.0779

Erbium Oxide

April 22nd. 1910.
10:45 P.M.

NO. 2.

Temp. 26°.8 C

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
14°42'	.9673	14.7	.90	1550	7.63
17°21'	.9545	176	3.10	5650	25.7
17° 8'	.9556	206	3.40	6100	27.5
17°21'	.9545	352	4.50	7850	36.6
17°34'	.9534	483	5.80	9225	42.8
17°15'	.9550	572	6.80	10000	46.6
17°15'	.9550	663	7.90	10450	51.7
16°56'	.9566	737	8.90	11250	53.3
17° 8'	.9556	865	11.10	12300	57.3
17° 8'	.9556	930	13.40	13150	57.7
16°49'	.9572	1073	15.20	13750	63.5
16°43'	.9577	1163	17.40	14300	66.3
16°49'	.9572	1241	19.40	14800	68.3
16°30'	.9588	1361	22.50	15300	72.4

Mass of specimen 0.859 gr. Length 2.48 cm. Diam. 0.3885 cm.

Volume " " 0.2938 $cm.^3$ Area cross section 0.1185 $cm.^2$

Density 2.93 Constant k= 0.0779

Erbium Oxide

April 25th. 1910. NO. 3. Temp.28°.5 C.
3:40 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
14° 2'	.9702	14.0	.90	1550	7.26
16°53'	.9569	114	3.10	5650	16.4
16°40'	.9580	195	3.50	6200	25.5
16°33'	.9586	350	4.50	7850	36.3
16°33'	.9586	477	5.80	9225	42.0
16°27'	.9591	565	6.80	10000	45.8
16°40'	.9580	674	7.90	10450	52.3
16°27'	.9591	743	8.95	11250	56.2
16°20'	.9596	913	11.00	12250	60.5
16°20'	.9596	1023	13.20	13100	63.5
16°20'	.9596	1079	14.90	13650	64.0
16° 8'	.9606	1147	16.90	14200	65.5
16° 8'	.9606	1210	18.80	14650	67.0
15°41'	.9628'	1339	21.70	15200	71.3

Mass of specimen 0.859 gr. Length 2.48 cm. Diam.0.3885 cm.

Volume " " 0.2938 $cm.^3$ Area cross section 0.1185 $cm.^2$

Density " " 2.93 Constant k = 0.0779

Erbium Oxide

April 25th. 1910. NO. 4. Temp. 23°.0 C
8:30 P.M.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
11°42'	.9792	11.7	.90	1550	6.00
14°54'	.9664	169	3.10	5650	24.1
15°24'	.9641	196	3.40	6100	26.2
17°23'	.9543	350	4.50	7850	36.4
16°38'	.9630	483	5.80	9225	42.3
15° 2'	.9658	553	6.80	10000	44.6
15° 2'	.9658	645	7.90	10450	49.7
16°41'	.9579	727	8.90	11250	52.6
16°38'	.9585	852	11.10	12250	52.9
16°34'	..9585	908	13.10	13050	56.7
16°41'	.9579	1001	15.10	13750	59.3
16° 8'	.9606	1096	17.10	14250	62.3
16°47'	.9574	1184	19.00	14700	65.6
16°34'	.9585	1217	21.60	15200	65.1

Mass of specimen 0.859 gr. Length 2.48 cm. Diam. 0.3885 cm.

Volume " " 0.2838 cm.^{3} Area cross section 0.1185 cm.^{2}

Density " " 2.93 Constant k = 0.0779

Terbium Oxide.

April 20th. 1910. NO. 1. Temp. 25°.0 C
10:45 P.M.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
0	0	0	.88	1600	0
18°38'	.9476	156	3.10	5650	24.5
18°19'	.9493	188	3.40	6100	27.3
18°19'	.9493	312	4.40	7600	36.2
18°13'	.9499	453	5.60	8900	44.9
18° 7'	.9504	537	6.60	9750	48.6
18° 0°	.9511	615	7.80	10600	51.0
17°47'	.9522	678	8.80	11200	53.3
17°35'	.9533	813	10.90	12200	58.6
17°25'	.9542	907	13.00	13000	61.3
17°35'	.9533	986	14.80	13600	63.7
17°16'	.9549	1070	16.80	14150	66.4
17°12'	.9553	1145	18.90	14650	68.6
17°22'	.9544	1256	22.10	15250	72.3

Mass of specimen 0.705 gr. Length 2.66 cm. Diam.0.4131 cm.

Volume " " 0.3564 $cm.^3$ Area cross section 0.1340 $cm.^2$

Density " " 1.97 Constant k = 0.0838

This specimen was obtained from the Chemistry Department and it is claimed to be only about 2% pure with a large proportion of Erbium oxide.

Terbium Oxide.

April 23rd. 1910. NO. 2. Temp. 22°.0 C.
4:45 P.M.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
2°22'	.9991	2.36	1.00	1800	1.09
18°12'	.9500	159	3.10	5650	24.8
18° 5'	.9506	195	3.50	6100	28.2
17°46'	.9523	329	4.50	7850	36.9
17°40'	.9528	467	5.70	8900	45.8
17°40'	.9528	550	6.80	10000	48.4
17°34'	.9534	624	7.90	10450	52.4
17°34'	.9534	694	8.90	11250	54.2
17°27'	.9540	821	11.00	12250	58.8
17°46'	.9523	917	13.00	13000	62.0
17°46'	.9523	999	15.10	13700	64.0
17°15'	.9550	1084	17.00	14200	67.0
16°55'	.9567	1178	19.00	14700	70.2
17° 2'	.9562	1280	22.20	15250	73.7

Mass of specimen 0.705 gr. Length 2.66 cm. Diam. 0.4131 cm.

Volume " " 0.3564 $cm.^3$ Area cross section 0.1340 $cm.^2$

Density " " 1.97 Constant k = 0.0838

This specimen was obtained from Chemsitry Dep't. and it is about 2% pure with a large proportion of Erbium oxide.

Yttrium Oxide (A)

April 18th.1910.
7 P.M.

Temp.24°.0 C

NO. 1.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
0	0	0	0	0	0
13°55'	.9706	134	3.10	5650	18.0
16°46'	.9575	154	3.40	6100	19.4
16°49'	.9572	287	4.54	7850	28.1
17°58'	.9512	366	5.80	9225	30.2
17°46'	.9523	417	7.90	10450	30.8
17°57'	.9513	527	9.00	11300	36.1
17°50'	.9520	660	11.10	12300	41.5
16°43'	.9577	715	13,20	13100	42.0
16°43'	.9577	743	15.10	13700	41.8
17°57'	.9513	906	16.63	14100	49.7
16°43'	.9577	1008	18.70	14600	53.3
16°43'	.9577	1050	22.00	15250	53.0

Mass of specimen 0.813 gr. Length 2.31 cm. Diam. 0.4139 cm.

Volume " " 0.3107 $cm.^3$ Area cross section 0.1345 $cm.^2$

Density " " 2.61 Constant k = 0.0737

Yttrium Oxide (A)

April 19th.1910. NO. 2. Temp.22°.5 C
8:00 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
12°36'	.9759	12.6	.88	1600	6.01
17°38'	.9530	123	3.10	5650	16.0
16°46	.9575	146	3.40	6100	18.4
17°51'	.9519	246	4.50	7850	24.2
18°27'	.9486	348	6.00	9550	28.1
18°37'	.9486	412	6.80	10000	32.0
18°27'	.9486	480	7.90	10450	35.7
18° 5'	.9506	528	8.90	11250	36.4
17°33'	.9535	640	11.20	12350	40.0
18°18'	.9494	837	13.20	13100	49.8
18°11	.9501	1140	15.20	13750	64.3
18° 5'	.9506	1203	17.40	14300	65.4
18°11'	.9501	1257	19.30	14750	66.1
18° 5'	.9506	1359	22.90	15400	68.3

Mass of specimen 0.813 gr. Length 2.31 cm. Diam. 0.4139 cm.

Volume " " 0.3107 cm.^{3} Area cross section 0.1345 cm.^{2}

Density " " 2.61 Constant k = 0.0737

Yttrium Oxide (A)

April 22nd.1910. NO.3.. Temp. 21°.8 C
4:00 P.M.

θ°	COS θ°	B°	I	H	A x 10^4
0	0	0	0	0	0
16°10'	.9605	16.0	.90	1550	7.93
19°58'	.9399	161	3.10	5650	22.3
18°53'	.9462	185	3.60	6350	22.7
20° 6'	.9391	295	4.70	8000	28.9
19°44'	.9413	404	5.70	9000	35.1
18°32'	.9481	469	7.00	10050	36.2
19° 1'	.9454	549	8.10	10750	39.9
19°44'	.9413	590	9.20	11400	40.6
18°17'	.9495	672	11.50	12450	41.8
19° 1'	.9454	862	15.80	13900	48.3
18°53'	.9462	919	17.8	14400	49.7
18°51'	.9464	959	20.0	14900	50.1
18°51'	.9464	1054	22.8	15350	53.5

Mass of specimen 0.813 gr. Length 2.31 cm. Diam. 0.4139 cm.

Volume " " 0.3107 $cm.^3$ Area cross section 0.1345 $cm.^2$

Density " " 2.61 Constant k = 0.0737

Yttrium Oxide (A)

April 23rd.1910.
8:25 P.M.

NO. 4.

Temp. 21°.0 C

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
0	0	0	0	0	0
17°25'	.9542	67	3.10	5650	9.15
17°25	.9542	86	3.40	6100	10.9
17°25'	.9542	169	4.50	7850	16.7
17° 8"	.9557	253	5.90	9200	21.2
16°59"	.9564	317	7.00	10050	24.3
16°59'	.9564	373	8.00	10700	26.9
17°19'	.9547	414	9.00	11300	28.3
16°21	.9596	487	11.30	12400	30.1
16°59'	.9564	561	13.40	13150	32.0
16°59"	.9564	624	15.30	13750	34.9
16°53'	.9569	695	17.50	14350	37.3
16°53"	.9569	743	19.50	14800	38.7
17°19"	.9547	811	22.70	15350	40.8

Mass of specimen 0.813 gr. Length 2.31 cm. Diam. 0.4139 cm.

Volume " " 0.3107 $cm.^3$ Area cross section 0.1345 $cm.^2$

Density " " 2.61 Constant k = 0.0737

Yttrium Oxide (B)

April 19th.1910.
8:30 P.M.

NO. 1.

Temp. 22°.5 C

θ°	Cos θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
12°30'	.9763	12.5	.90	1550	4.78
17°57'	.9513	150	3.10	5650	20.2
17°19'	.9547	173	3.40	6100	21.5
18°22'	.9491	270	4.50	7850	26.2
17°44'	.9525	372	5.60	8900	31.7
18° 9"	.9502	447	6.60	9750	34.9
17°44'	.9525	519	7.80	10600	37.1
18° 9'	.9502	570	8.80	11200	38.8
17°44"	.9525	635	10.80	12150	39.7
17°44"	.9525	708	12.80	12950	41.6
17°44"	.9525	777	14.60	13650	43.3
17°31'	.9536	864	15.90	13900	47.2
17°37'	.9531	906	18.30	14550	47.4
17°31'	.9536	978	21.90	15250	48.7

Mass of specimen 0.748 gr. Length 2.29 cm. Diam.0.4194 cm.

Volume " " 0.3162 cm.^{3} Area cross section 0.1381 cm.^{2}

Density " " 2.36 Constant k = 0.0724

This specimen was made Erbium Bromide solution.

Yttrium Oxide (B)

April 22nd. 1910. NO. 2. Temp. 23°.3 C
4:30 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
17° 5'	.9559	17,1	.90	1550	8.36
18°21'	.9492	169	3.10	5650	22.8
18°21'	.9492	185	3.40	6100	23.1
18°15'	.9497	282	4.50	7850	27.40
18° 2'	.9509	387	5.50	8800	33.5
18° 9'	.9502	468	6.80	10000	35.6
17°43'	.9526	534	8.00	10700	38.0
18° 9'	.9502	578	8.90	11250	39.1
18° 9'	.9502	650	11.10	12300	40.3
18°21'	.9492	828	15.50	13800	45.7
18° 9'	.9502	888	17.60	14350	47.1
18° 9'	.9502	968	19.70	14850	49.7
17°43'	.9526	1020	23.50	15450	50.2

Mass of specimen 0.748 gr. Length 2.28 cm. Diam. 0.4194 cm.

Volume " " 0.3162 $cm.^3$ Area cross section 0.1381 $cm.^2$

Density " " 2.36 Constant k = 0.0724

This specimen was made with Erbium Bromide solution.

Yttrium Oxide (B)

April 23rd. 1910. NO. 3. Temp. 22°.0 C.
9:30 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
13°51'	.9709	13.9	.90	1550	6.69
16°10'	.9605	142	3.10	5650	18.9
15°38'	.9630	169	3.50	6200	20.5
16°17'	.9599	246	4.50	7850	23.6
15°22'	.9642	339	5.80	9225	27.6
16°23'	.9594	439	6.80	10000	33.1
16°23'	.9594	500	7.90	10450	36.1
16°23'	.9594	547	8.90	11250	36.7
17° 2'	.9561	620	11.10	12300	38.6
16°23'	.9594	688	13.20	13100	39.6
16°35'	.9584	758	15.20	13750	41.7
16°35'	.9584	821	17.20	14300	42.4
16°17'	.9599	878	19.40	14800	44.7
16° 4'	.9609	956	22.80	15350	47.0

Mass of specimen 0.748 gr. Length 2.29 cm. Diam. 0.4194 cm.

Volume " " 0.3162 $cm.^3$ Area cross section 0.1381 $cm.^2$

Density " " 2.36 Constant k = 0.0724

This specimen was made with Erbium Bromide solution.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Neodymium Oxide.

April 20th.1910.
8:10 P.M.

NO. 1.

Temp. 24°.0 C

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
3° 0'	.9986	3.00	.88	1600	1.40
17°26'	.9541	63.0	3.10	5650	8.75
17°32'	.9553	78.0	3.40	6100	10.00
17° 7'	.9556	136	4.50	7850	13.6
17° 0'	.9563	188	5.60	8900	16.7
17° 7'	.9556	223	6.70	9800	17.8
17°13'	.9552	257	7.80	10600	19.0
17° 7'	.9556	287	8.70	11150	20.1
18°57'	.9462	247	10.80	12150	22.6
17° 7'	.9556	387	12.90	13000	23.3
17°13'	.9552	425	14.80	13600	24.5
18°53'	.9462	466	16.70	14150	26.0
16°54'	.9568	497	18.80	14650	26.5
16°54'	.9568	545	22.10	15250	27.9

Mass of specimen 0.745 gr. Length 2.45 cm. Diam. 0.4535 cm.

Volume " " 0.3957 cm.^{3} Area cross section 0.1615 cm.^{2}

Density " " 1.88 Constant k = 0.0747

Neodymium Oxide.

April 22nd. 1910.
11:20 P.M.

NO. 2.

Temp. 27°.1 C.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
2°59'	.9986	2.98	1.00	1800	1.24
15°49'	.9621	73	3.10	5650	10.0
15°22'	.9642	87	3.40	6100	11.0
15°55'	.9617	147	4.50	7850	14.6
15°55'	.9617	207	5.60	8900	18.1
15°49'	.9621	244	6.80	10000	19.0
15°42'	.9627	278	7.90	10450	20.7
15° 3'	.9657	305	8.80	11200	21.10
15°49'	.9621	362	10.90	12200	23.1
15°22'	.9642	414	13.00	13000	25.0
15° 9'	.9652	459	14.90	13650	26.0
15°42'	.9627	498	16.80	14150	27.6
15°42'	.9627	529	18.70	14600	28.1
15°29'	.9637	571	22.20	15250	29.1

Mass of specimen 0.745 gr. Length 2.45 cm. Diam. 0.4535 cm.

Volume " " 0.3957 $cm.^3$ Area cross section 0.1615 $cm.^2$

Density " " 1.88 Constant k = 0.0747

Neodymium Oxide.

April 25th. 1910. NO. 3. Temp. 30°.8 C.
4:10 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
1°27'	.9997	1.45	.90	1550	.701
16°21'	.9596	34.0	3.10	5650	4.71
17°37'	.9531	84	3.40	6100	10.8
18°28'	.9485	140	4.50	7850	14.1
17°31'	.9536	198	5.60	8900	17.4
17°31'	.9536	231	6.70	9800	18.5
17°25'	.9542	265	7.70	10500	19.8
17°37'	.9534	291	8.90	11250	20.0
17°56'	.9514	357	10.80	12150	23.1
17°56'	.9514	411	12,80	12950	24.9
17°57'	.9513	458	14.70	13550	26.5
17°44'	.9525	498	16.70	14150	27.6
17°31'	.9536	522	18.60	14600	28.1
17°25'	.9542	563	21.20	15150	29.1

Mass of specimen 0.745 gr. Length 2.45 cm. Diam. 0.4535 cm.

Volume " " 0.3957 $cm.^3$ Area cross section 0.1615 $cm.^2$

Density " " 1.88 Constant k = 0.0747

Neodymium Sulfate

April 20th. 1910. 1:20 P.M.		NO. 1.		Temp. 21°.5 C.	
θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
2°26'	.9991	2.43	.90	1550	.888
18°40'	.9474	88	3.10	5650	9.32
19°14'	.9442	91	3.40	6100	8.96
19°22'	.9434	154	4.50	7850	11.75
19°26'	.9430	214	5.60	8900	14.42
19°14"	.9442	259	6.60	9750	15.91
19°14'	.9442	301	7.80	10600	17.00
19°29'	.9427	335	8.90	11250	17.90
19°14'	.9442	395	11.00	12250	19.30
19°20"	.9436	454	13.20	13100	20.80
19°20'	.9436	495	15.10	13700	21.60
19°14"	.9442	534	17.1	14250	22.40
19° 1"	.9454	574	19.30	14750	23.30
19° 1'	.9454	627	22.80	15350	24.40

Mass of specimen 0.897 gr. Length 2.66 cm. Diam. 0.4400 cm.

Volume " " 0.4046 $cm.^3$ Area cross section 0.1521 $cm.^2$

Density " " 2.21 Constant k = 0.0566

Neodymium Sulfate

April 22nd. 1910. NO. 2. Temp. 25°.5 C
7:40 P.M.

θ°	cos θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
2°26'	.9991	2.43	1.00	1800	.763
18°57'	.9458	75	3.10	5650	7.94
19°22'	.9434	85	3.40	6100	8.35
19°22'	.9434	146	4.50	7850	11.15
19°22'	.9434	196	5.80	9225	12.75
18°51'	.9464	244	6.80	10000	14.50
18°57'	.9459	286	7.90	10450	16.30
19° 4'	.9456	319	8.90	11250	16.90
19° 4'	.9451	379	11.10	12300	18.40
19°10'	.9446	431	13.40	13150	19.60
19° 4'	.9451	467	15.20	13750	20.30
18°57'	.9458	499	17.20	14300	20.90
18°51'	.9464	538	19.20	14750	21.80
18°51'	.9464	589	21.90	15250	23.10

Mass of specimen 0.897 gr. Length 2.66 cm. Diam. 0.4400 cm.

Volume " " 0.4056 $cm.^3$ Area cross section 0.1521 $cm.^2$

Density " " 2.21 Constant k = 0.0566

Yttrium Oxide D.

April 20th. 1910. NO. 1. Temp. 24°.5 C.
10:00 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
1°13'	.9998	1.21	.88	1600	.430
15°45'	.9625	43.0	3.10	5650	4.50
15°25'	.9640	51	3.40	6100	4.94
15°15'	.9648	89	4.50	7850	6.78
15° 5'	.9655	122	5.60	8900	8.09
15°15'	.9648	147	6.80	10000	8.66
14°59'	.9660	167	7.90	10450	9.40
14°59'	.9660	186	8.80	11200	9.78
14°58'	.9660	225	10.90	12200	10.80
14°59'	.9660	252	13.00	13000	11.40
14°52'	.9665	282	14.90	13650	12.10
14°59'	.9660	309	17.00	14200	12.80
14°59'	.9660	332	19.20	14750	13.20
14°59'	.9660	359	22.30	15300	13.8

Mass of specimen 0.610 gr. Length 2.91 cm. Diam. 0.4198 cm.

Volume " " 0.4027 cm.^{3} Area cross section 0.1348 cm.^{2}

Density " " 1.51 Constant k = 0.0581

This specimen was obtained from the Chemistry Department and it is supposed to be nearly 90% pure.

Yttrium Oxide D.

April 23rd. 1910. NO. 2. Temp. 20°.2 C.
4:00P.M.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
0°21'	1.0000	.35	.90	1550	.366
17P59'	.9511	44	3.10	5650	4.65
17°59'	.9511	53	3.40	6100	5.19
17°59'	.9511	93	4.50	7850	7.08
17°25'	.9542	128	5.90	9200	8.28
17°21'	.9545	152	7.00	10050	9.00
17° 0'	.9563	174	8.10	10750	9.62
17°25'	.9542	195	9.10	11350	10.20
17°21'	.9545	229	11.50	12450	10.90
17°14'	.9551	263	13.70	13250	11.80
17° 0'	.9563	291	16.00	13900	12.40
17° 8'	.9556	322	18.00	14450	13.20
17°14'	.9551	345	20.30	14950	13.70
16°42'	.9578	377	23.60	15450	14.00

Mass of specimen 0.610 gr. Length 2.91 cm. Diam. 0.4198 cm.

Volume " " 0.4027 $cm.^3$ Area cross section 0.1348 $cm.^2$

Density " " 1.51 Constant k = 0.0581

This specimen was obtained from the Chemistry Department and it is supposed to be nearly 90% pure.

Praseodymium Oxide

April 20th.1910. NO. 1. Temp. 22°.0C.
4:45 P.M.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
2°15'	.9992	2.25	.90	1550	.786
18°53'	.9462	35	3.10	5650	3.55
18° 5'	.9506	43	3.40	6100	4.01
17° 4'	.9560	75	4.50	7850	5.41
18° 2'	.9509	106	5.50	8800	6.85
18°45'	.9465	127	6.80	10000	7.26
18°45'	.9465	145	7.90	10450	7.92
18°38'	.9476	160	8.80	11200	8.17
18°38'	.9476	190	10.90	12200	8.90
18°38'	.9476	214	13.10	13050	9.36
18°38'	.9476	235	15.00	13650	9.84
18°24'	.9489	261	16.90	14200	10.50
18°31'	.9482	285	19.20	14750	11.02
18°24'	.9489	315	22.40	15300	11.73

Mass of specimen 0.749 gr. Length 2.62 cm. Diam.0.4535 cm.

Volume " " 0.4231 cm.^{3} Area cross section 0.1615 cm.^{2}

Density " " 1.77 Constant k = 0.0541

Praseodymium Oxide

April 22nd. 1910. NO. 2. Temp. 25°.5 C.
9:30 P.M.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
1°30'	1.0000	1.50	.90	1550	.524
18°47'	.9467	36	3.10	5650	3.65
15°46'	.9624	42	3.40	6100	3.87
18° 5'	.9506	70	4.50	7850	5.08
18°55'	.9460	100	5.60	8900	6.42
18°55'	.9460	120	6.80	10000	6.85
18°49'	.9466	141	7.90	10450	7.70
18°49'	.9466	155	8.90	11250	7.88
18°49'	.9466	185	11.20	12350	8.57
18°49'	.9466	209	13.30	13100	9.12
18°43'	.9471	232	15.30	13750	9.65
18° 5'	.9506	251	17.30	14300	10.00
18°25'	.9485	270	19.40	14800	10.40
18°13'	.9499	300	22.80	15350	11.12

Mass of specimen 0.749 gr. Length 2.62 cm. Diam. 0.4535 cm.

Volume " " 0.4231 cm.^{3} Area cross section 0.1615 cm.^{2}

Density " " 1.77 Constant k = 0.0541

Yttrium Oxide (C)

April 19th. 1910. NO. 1. Temp. 23°.0 C.
10:20 P.M.

θ°	COS θ	B°	I	H	A x 10^4
0	0	0	0	0	0
1°15"	.9998	1.25	.90	1550	.3.97
17°44'	.9525	39.0	3.10	5650	3.48
17°44'	.9525	50.0	3.40	6100	4.13
17°38'	.9530	87.0	4.50	7850	5.60
17°31'	.9536	122	5.60	8900	6.80
17°31'	.9536	136	6.80	10000	6.85
17°19'	.9547	168	7.90	10450	8.11
17°19'	.9547	187	8.80	11200	8.42
17°14"	.9551	215	10.90	12200	8.88
17°19'	.9547	246	13.00	13000	9.53
17°14"	.9551	269	15.00	13650	9.92
17° 6"	.9558	286	16.80	14150	10.15
17° 0'	.9563	308	19.00	14700	10.52
16°53'	.9569	336	22.00	15350	11.08

Mass of specimen 0.595 gr. Length 2.75 cm. Diam. 0.4125 cm.

Volume " " 0.4674 $cm.^3$ Area cross section 0.1336 $cm.^2$

Density " " 1.27 Constant k = 0.0481

This specimen was obtained from the Chemistry department.

It is estmated to be 90% pure with a trace of magnesium.

Yttrium Oxide (C)

April 22nd. 1910. NO. 2. Temp. 23°.3 C.
6:15 P.M.

θ°	COS θ	B°	I	H	$A \times 10^4$
0	0	0	0	0	0
1°21'	.9997	1.35	1.00	1800	.365
17°44'	.9525	36.0	3.10	5650	3.22
17°44'	.9525	45.0	3.50	6200	3.67
15°54'	.9617	76.0	4.60	7850	4.83
17°56'	.9514	110	5.90	9200	6.04
18°15'	.9497	129	6.90	10000	6.55
18°28'	.9485	147	8.00	10700	6.97
18°34'	.9480	163	8.90	11250	7.35
18°34'	.9480	195	11.20	12350	8.00
18°15'	.9497	219	13.40	13150	8.43
18°34'	.9480	239	15.30	13750	8.81
18°21'	.9492	261	17.40	14300	9.27
18°21'	.9492	276	19.20	14750	9.48
18° 9'	.9502	310	22.40	15300	10.25

Mass of specimen 0.595 gr. Length 2.75 cm. Diam.0.4125 cm.

Volume " " 0.4674 cm.^{3} Area cross section 0.1336 cm.^{2}

Density " " 1.27 Constant k = 0.0481

This specimen was obtained from the Chemistry department.

It is estimated to be about 90% pure with a trace of magnesium.

Glass Rod.

April 20th. 1910.
11:15 P.M.

Temp.25°.5 C

θ°	COS θ	B°	I	H	A x 10^5
0	0	0	0	0	0
0	0	0	.88	1600	0
0°24'	1.0000	0.40	3.10	5650	0.180
0°12'	1.0000	0.20	3.40	6100	0.084
1° 4'	.9998	1.06	4.50	7800	3.48
1°52'	.9995	1.85	5.60	8900	5.29
2°18'	.9992	2.30	6.70	9750	6.02
2°52'	.9987	2.85	7.80	10600	6.85
2°55'	.9987	2.91	8.70	11100	6.69
3°55'	.9977	3.91	10.90	12200	8.17
4°45'	.9966	4.75	13.00	13050	9.34
5°19'	.9957	5.31	16.90	14200	9.59
6°21'	.9939	6.35	18.00	14450	11.28
7°25'	.9916	7.41	19.00	15100	12.62
8°40'	.9886	8.66	22.10	15400	14.50

Mass of specimen 2.146 gr. Length 2.53 cm. Diam. 0.6750 cm.

Volume " " 0.9050 cm.^{3} Area cross section 0.3578 cm.^{2}

Density " " 2.50 Constant k = 0.0255

Phosphorbronze.

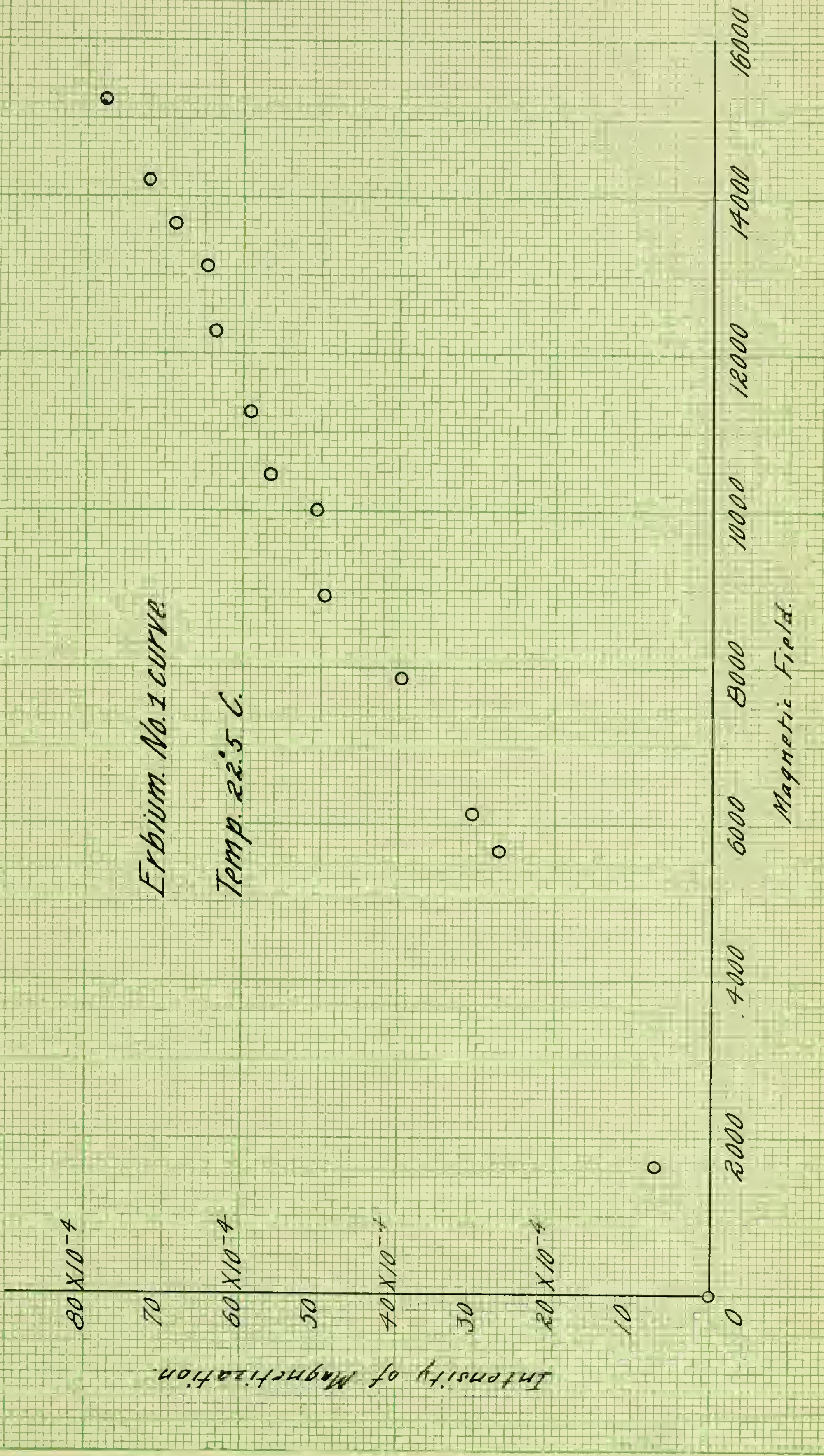
April 23rd. 1910. Temp. 20°. 0 C

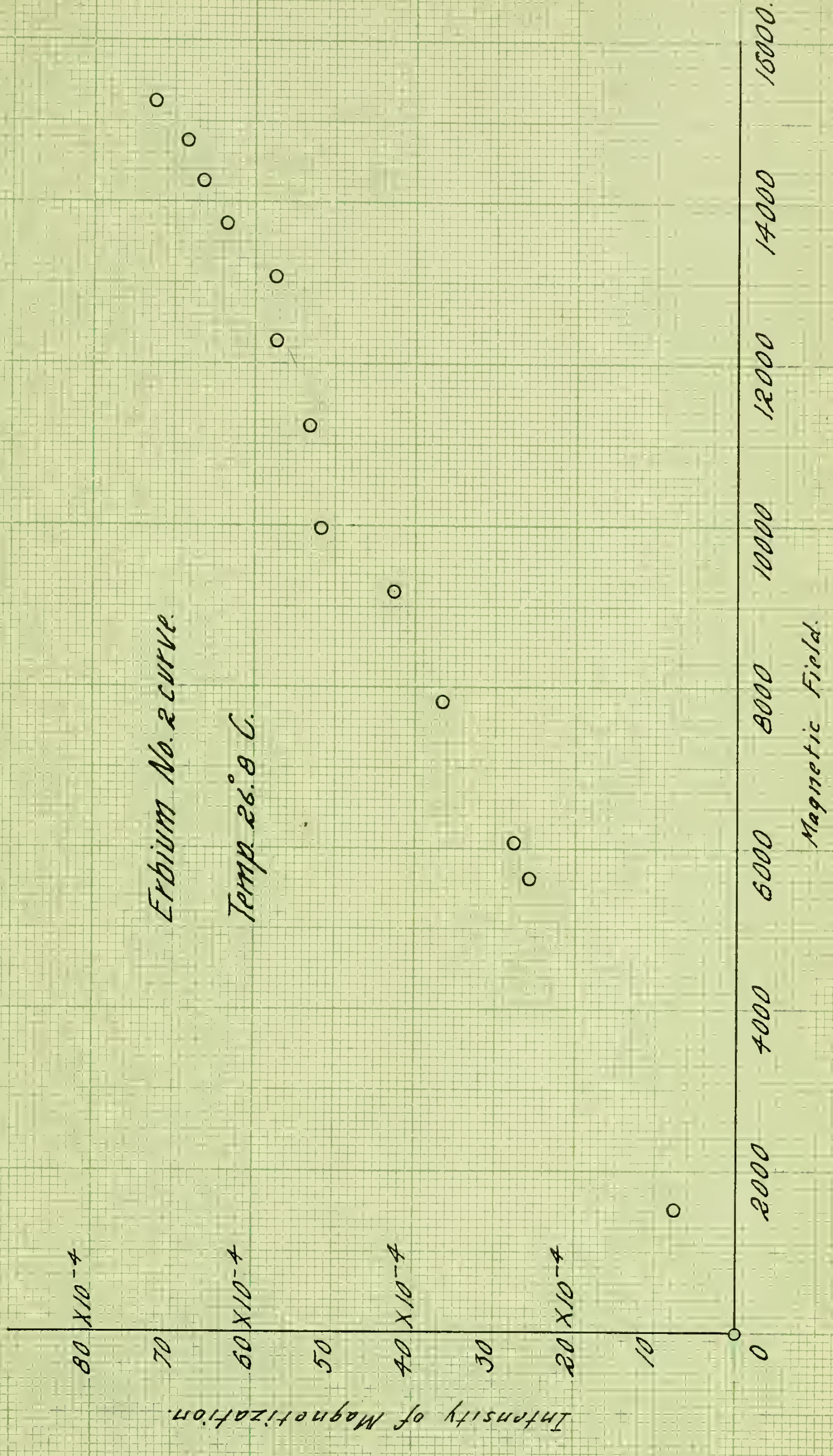
θ°	COS θ	B°	I	H	A x 10^5
0	0	0	0	0	0
1°28'	.9997	1.46	.80	1600	6.08
6°19'	.9941	6.13	3.10	5650	7.43
6°58'	.9926	6.96	3.40	6100	7.61
16°36'	.9583	16.60	4.50	7850	14.60
16°59'	.9564	23.00	5.80	9225	17.20
17°44'	.9525	25.70	6.80	10000	17.80
17°00'	.9563	29.00	7.90	10450	19.20
17°12'	.9553	31.20	8.90	11250	19.10
18° 9'	.9502	34.00	11.10	12300	19.20
17°18'	.9548	38.30	13.20	13100	20.20
17°31'	.9536	40.50	15.10	13700	20.50
17P24'	.9542	44.40	17.30	14300	21.50
16° 7'	.9607	46.00	19.40	14800	21.40
16°49'	.9572	48.80	21.90	15250	22.1-

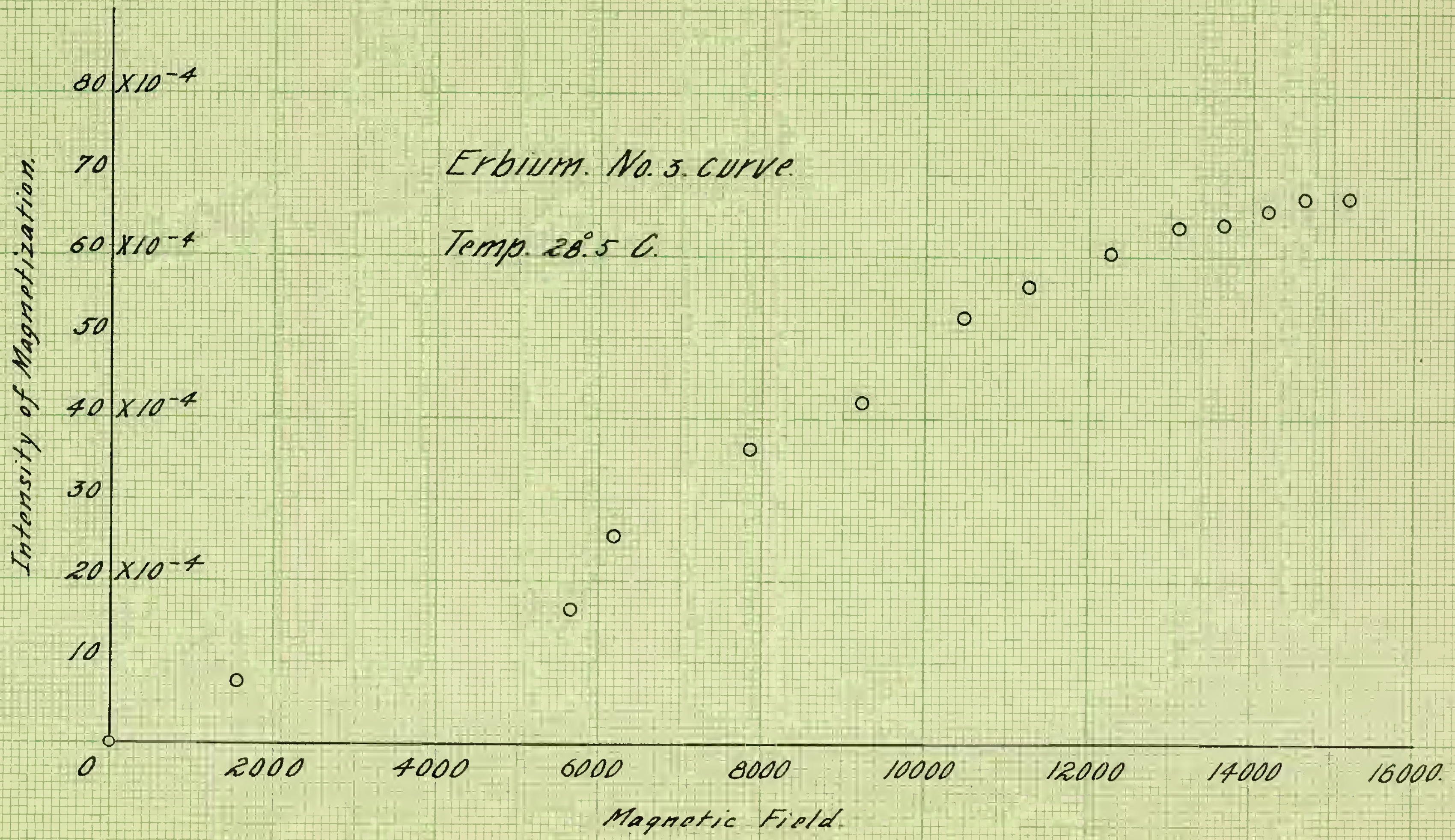
Mass of specimen 3.025 gr. Length 2.57 cm. Diam.0.4142 cm.

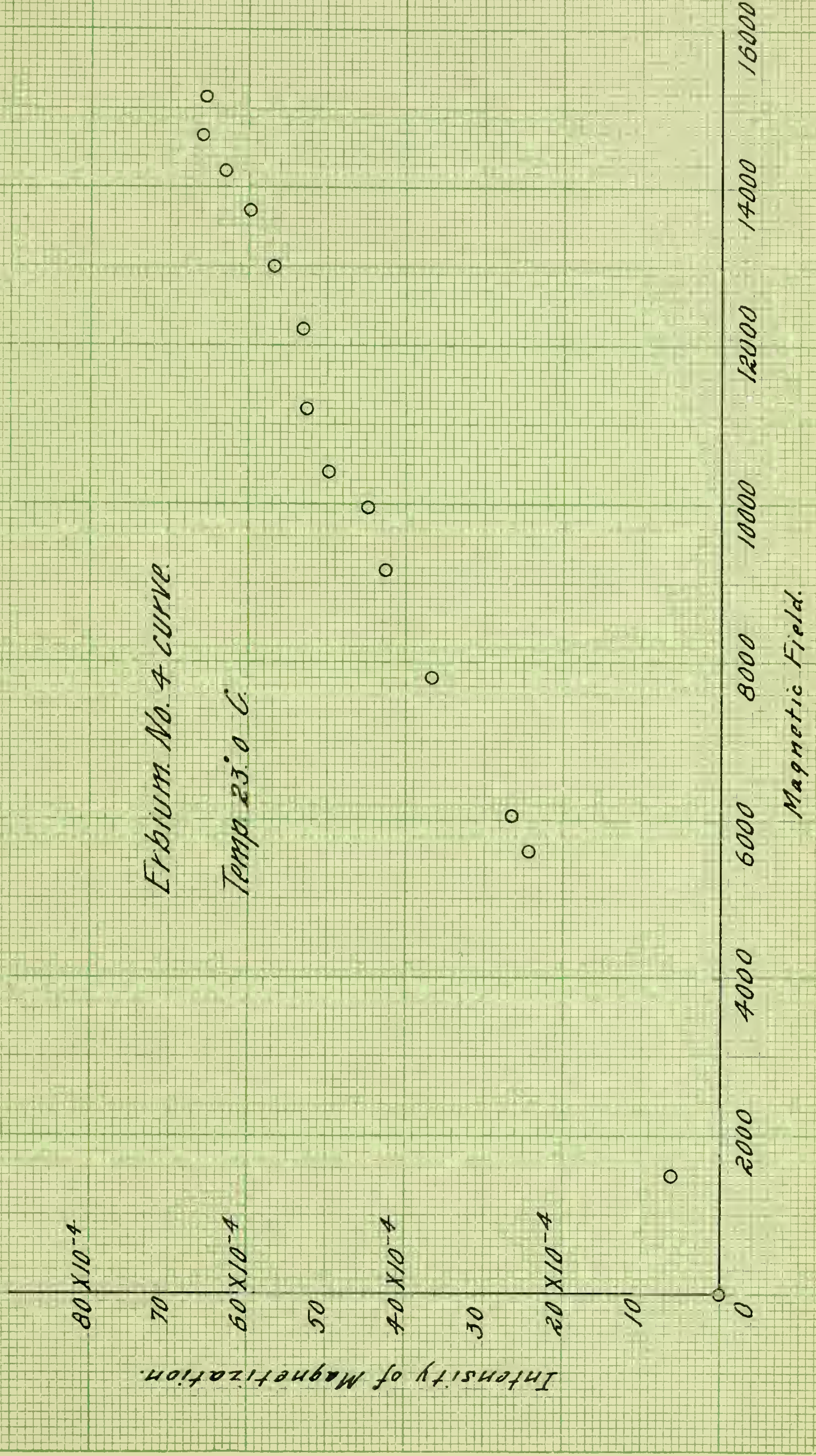
Volume " " 0.3462 $cm.^3$ Area cross section 0.1347 $cm.^2$

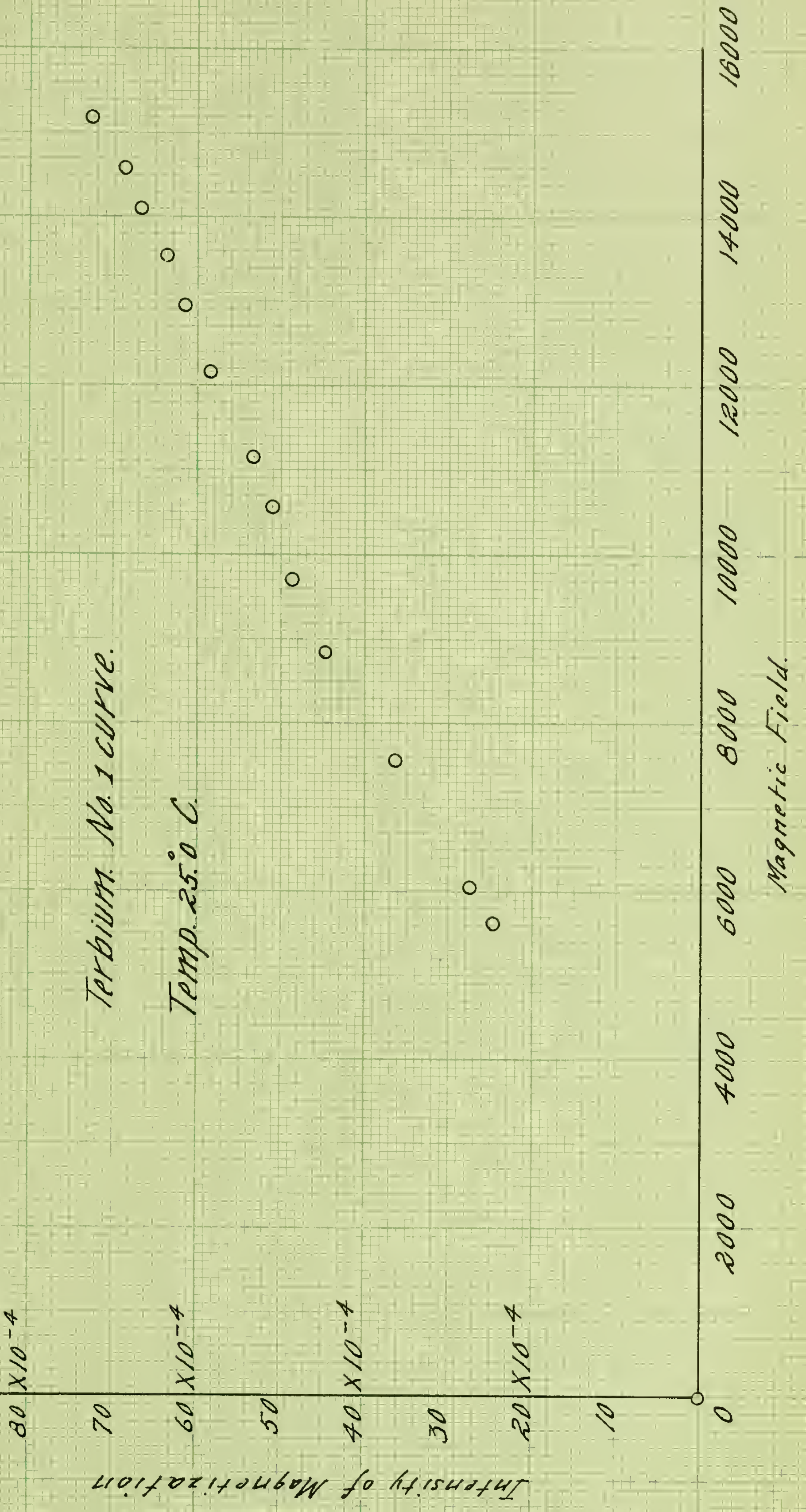
Density " " 8.73 Constant k = 0.0661

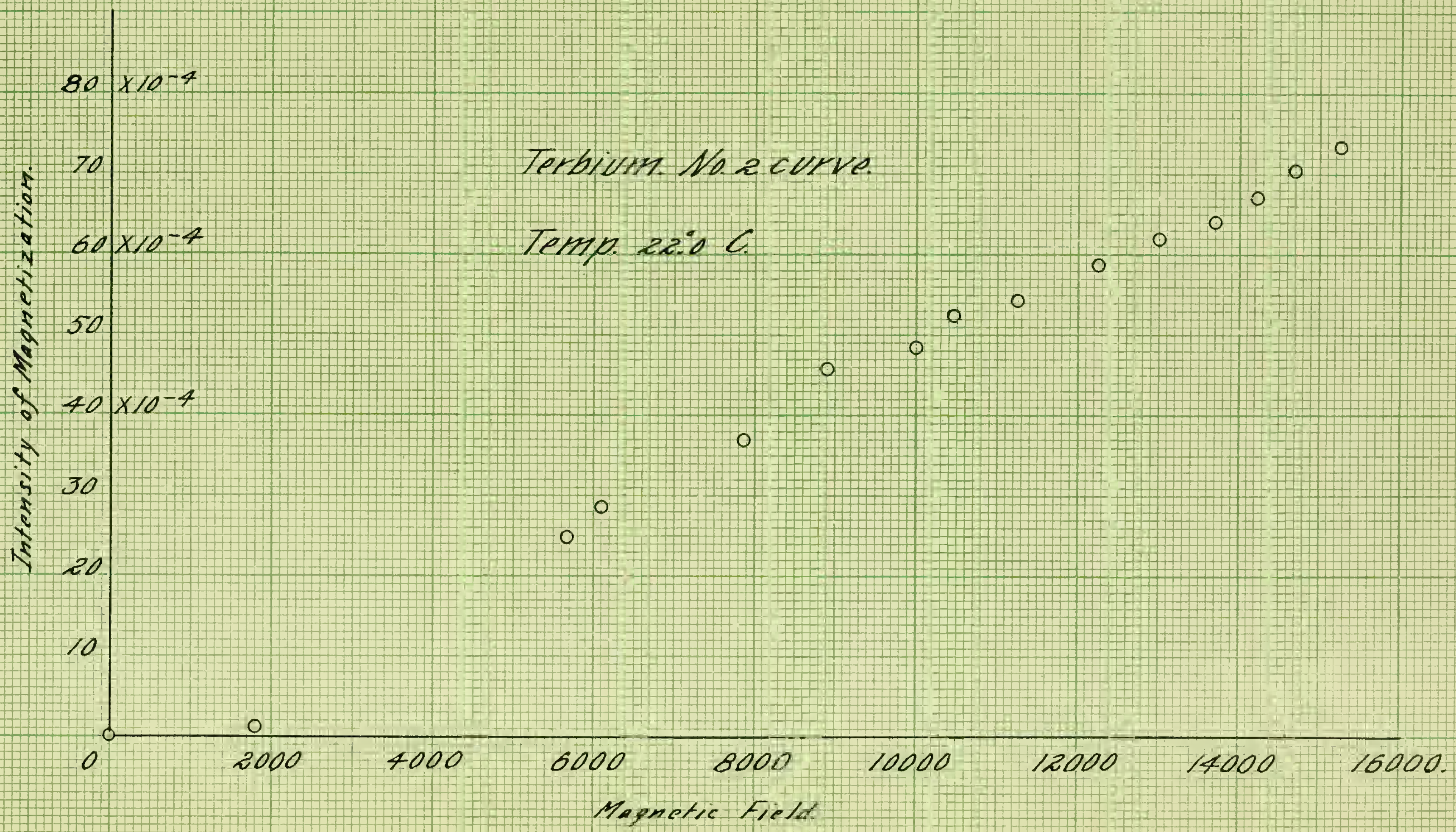

Erbium No. 1 curve
Temp. 22°5 C.
Magnetic Field.
Intensity of Magnetization.
0
2000
4000
6000
8000
10000
12000
14000
16000
10
20 X10⁻⁴
30
40 X10⁻⁴
50
60 X10⁻⁴
70
80 X10⁻⁴

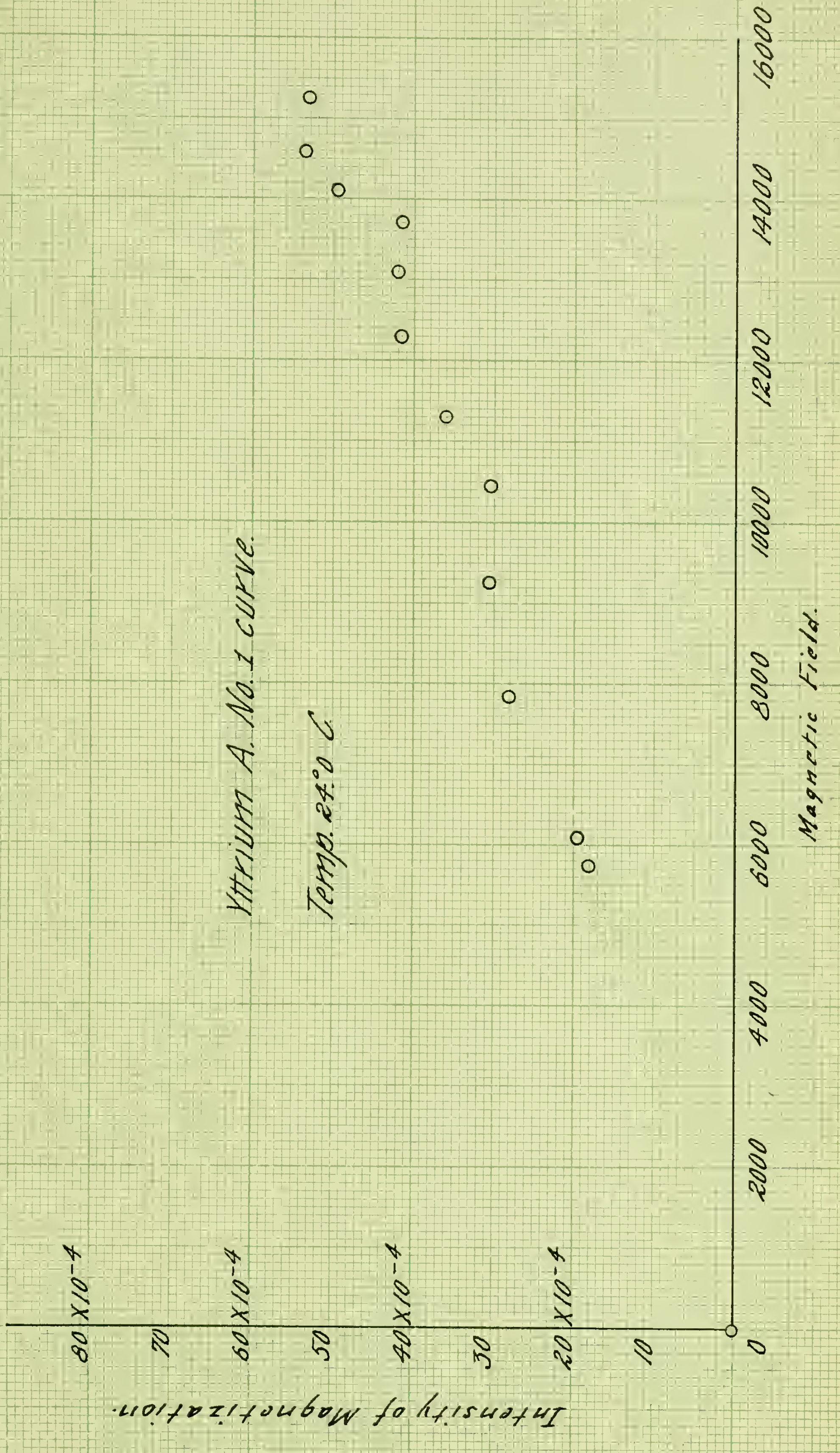

Erbium No. 2 curve
Temp. 26.8° C.
80 X10-4
70
60 X10-4
50
40 X10-4
30
20 X10-4
10
0
Intensity of Magnetization.
2000
4000
6000
8000
10000
12000
14000
16000.
Magnetic Field.

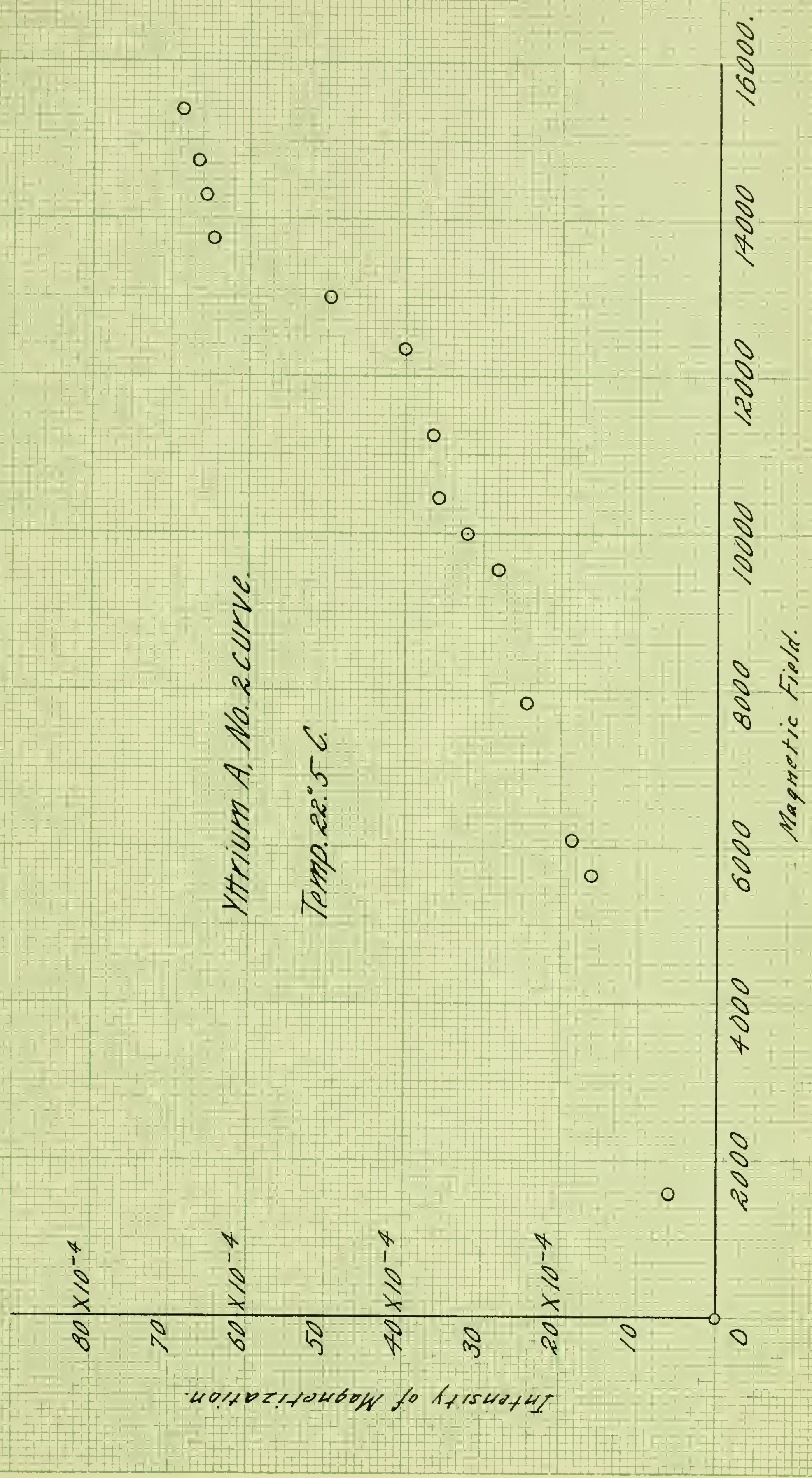

Erbium. No. 3. curve
Temp. 28°.5 C.
Intensity of Magnetization.
80 X10⁻⁴
70
60 X10⁻⁴
50
40 X10⁻⁴
30
20 X10⁻⁴
10
0
2000
4000
6000
8000
10000
12000
14000
16000.
Magnetic Field.

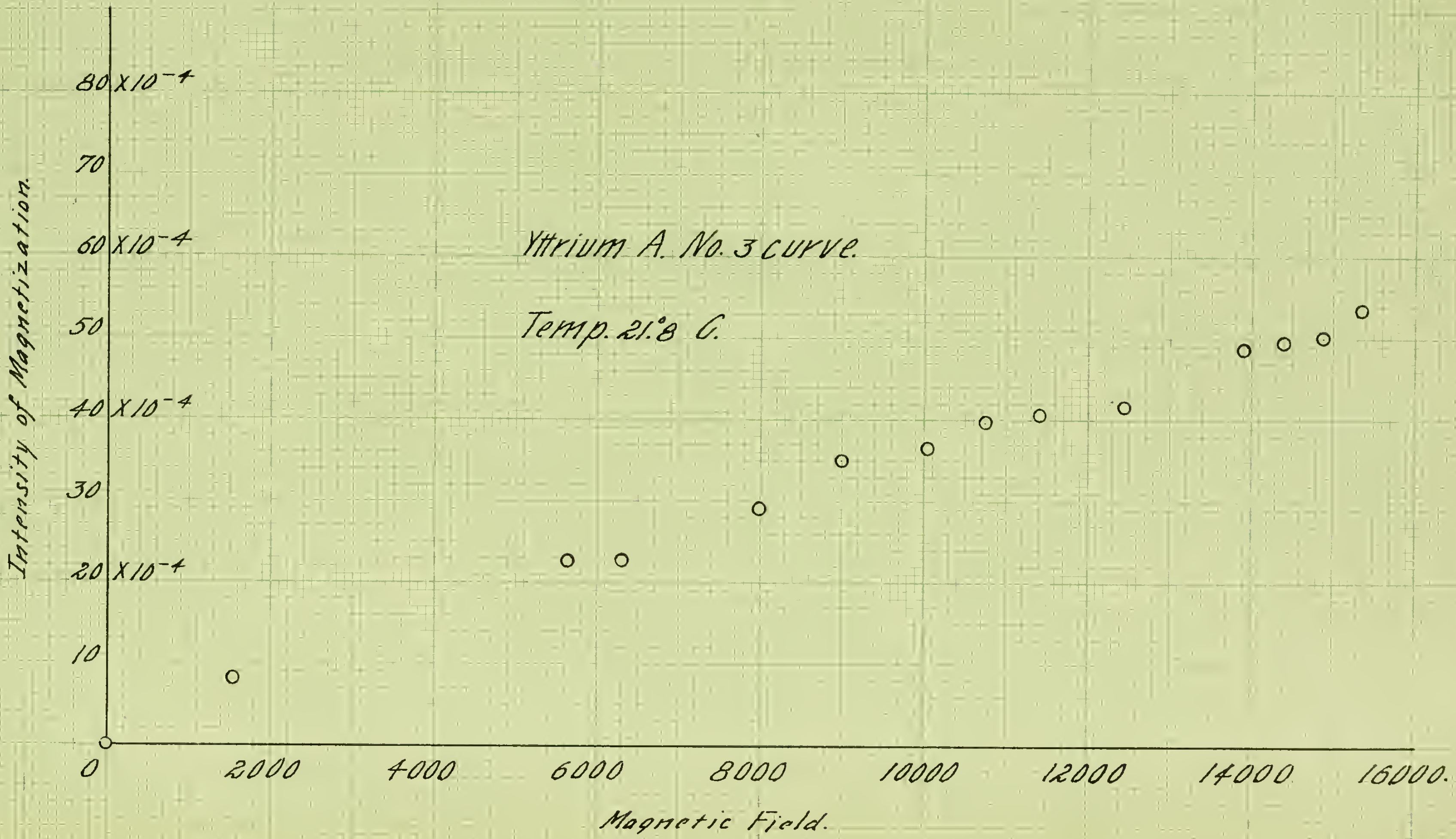

Erbium No. 4 curve
Temp 23.0 C.
Intensity of Magnetization.
80 X10⁻⁴
70
60 X10⁻⁴
50
40 X10⁻⁴
30
20 X10⁻⁴
10
0
2000
4000
6000
8000
10000
12000
14000
16000
Magnetic Field.


Terbium. No. 1 curve.
Temp. 25.0° C.
80 X10-4
70
60 X10-4
50
40 X10-4
30
20 X10-4
10
0
2000
4000
6000
8000
10000
12000
14000
16000
Magnetic Field.
Intensity of Magnetization


Terbium No 2 curve.
Temp. 22.0° C.
Intensity of Magnetization.
80 X10-4
70
60 X10-4
50
40 X10-4
30
20
10
0
2000
4000
6000
8000
10000
12000
14000
16000.
Magnetic Field

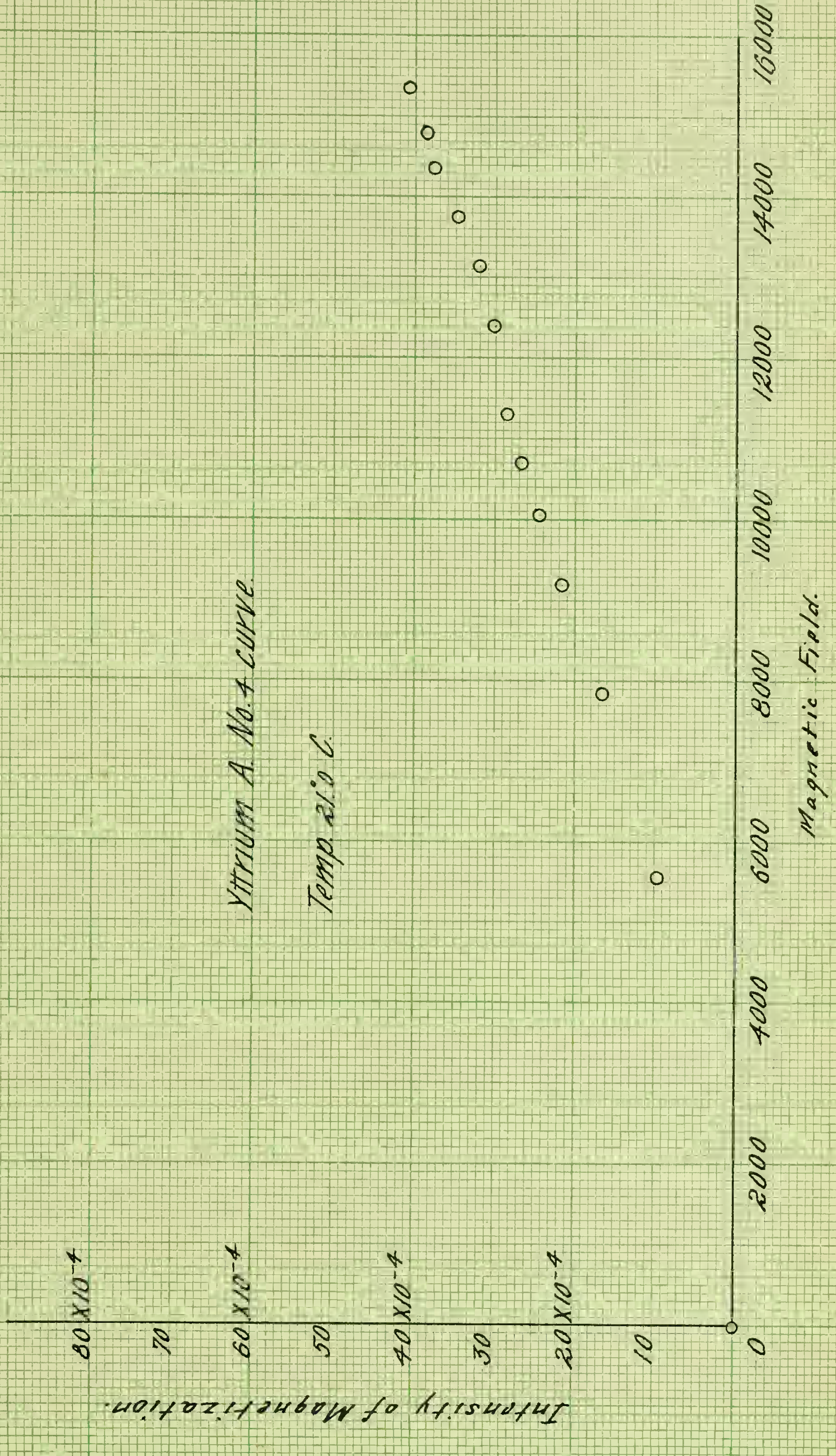

Yttrium A. No. 1 curve.
Temp. 24.0° C
Intensity of Magnetization.
80 X10-4
70
60 X10-4
50
40 X10-4
30
20 X10-4
10
0
2000
4000
6000
8000
10000
12000
14000
16000
Magnetic Field.


Yttrium A, No. 2 Curve.
Temp. 22°5 C.
Intensity of Magnetization.
Magnetic Field.
0
10
20 X10⁻⁴
30
40 X10⁻⁴
50
60 X10⁻⁴
70
80 X10⁻⁴
0
2000
4000
6000
8000
10000
12000
14000
16000.



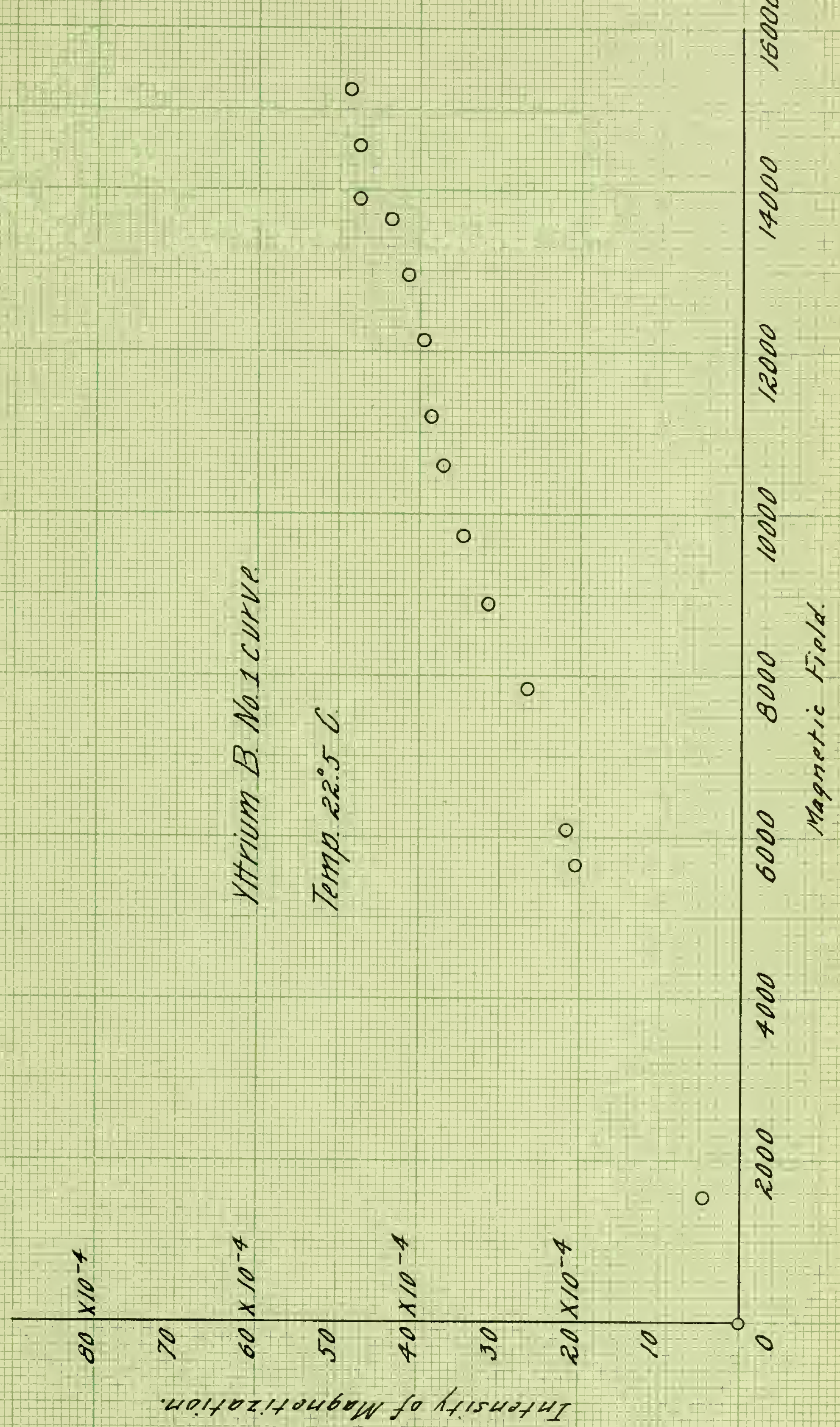
Yttrium A. No. 3 curve.

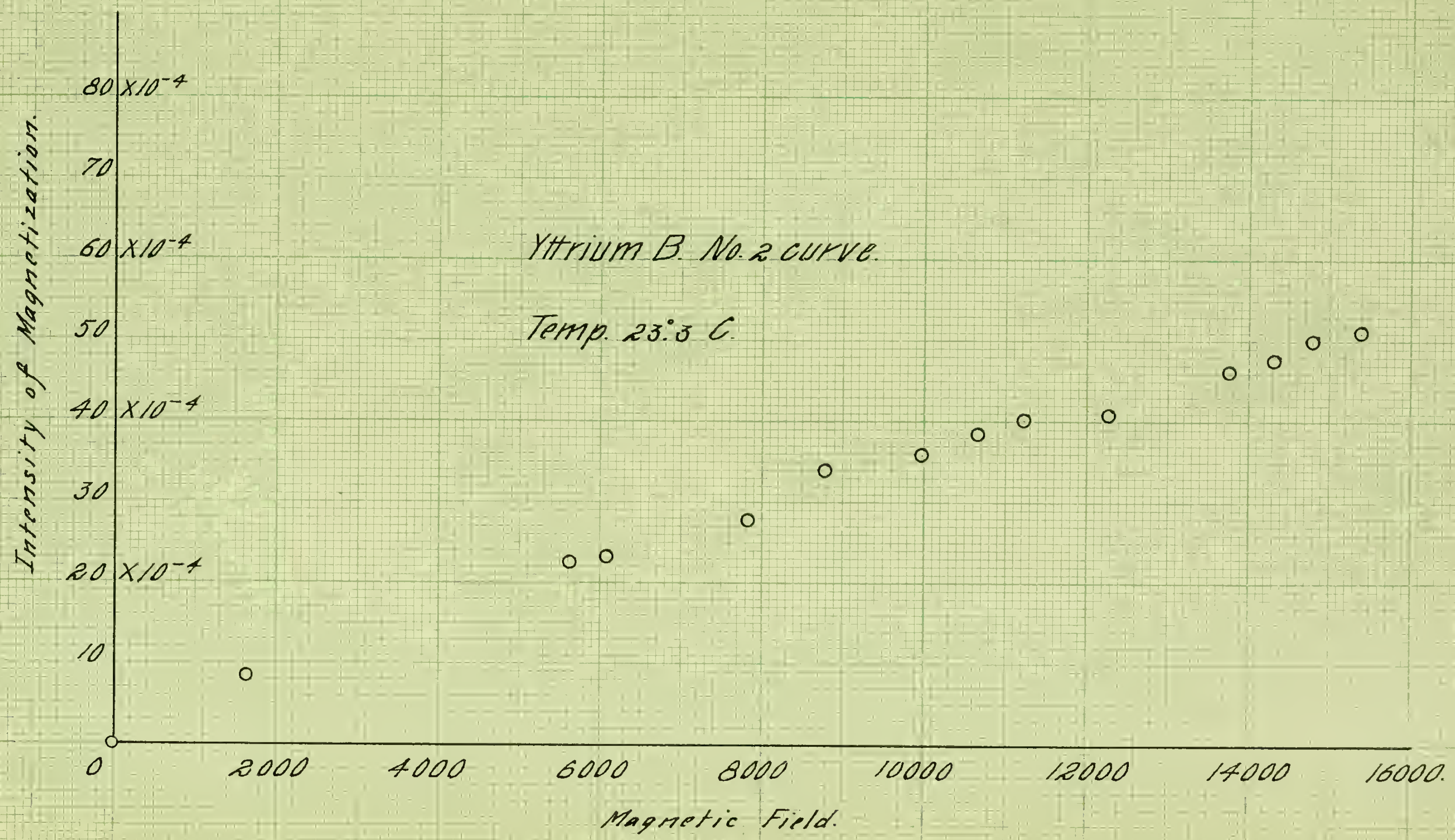
Temp. 21.°8 C.

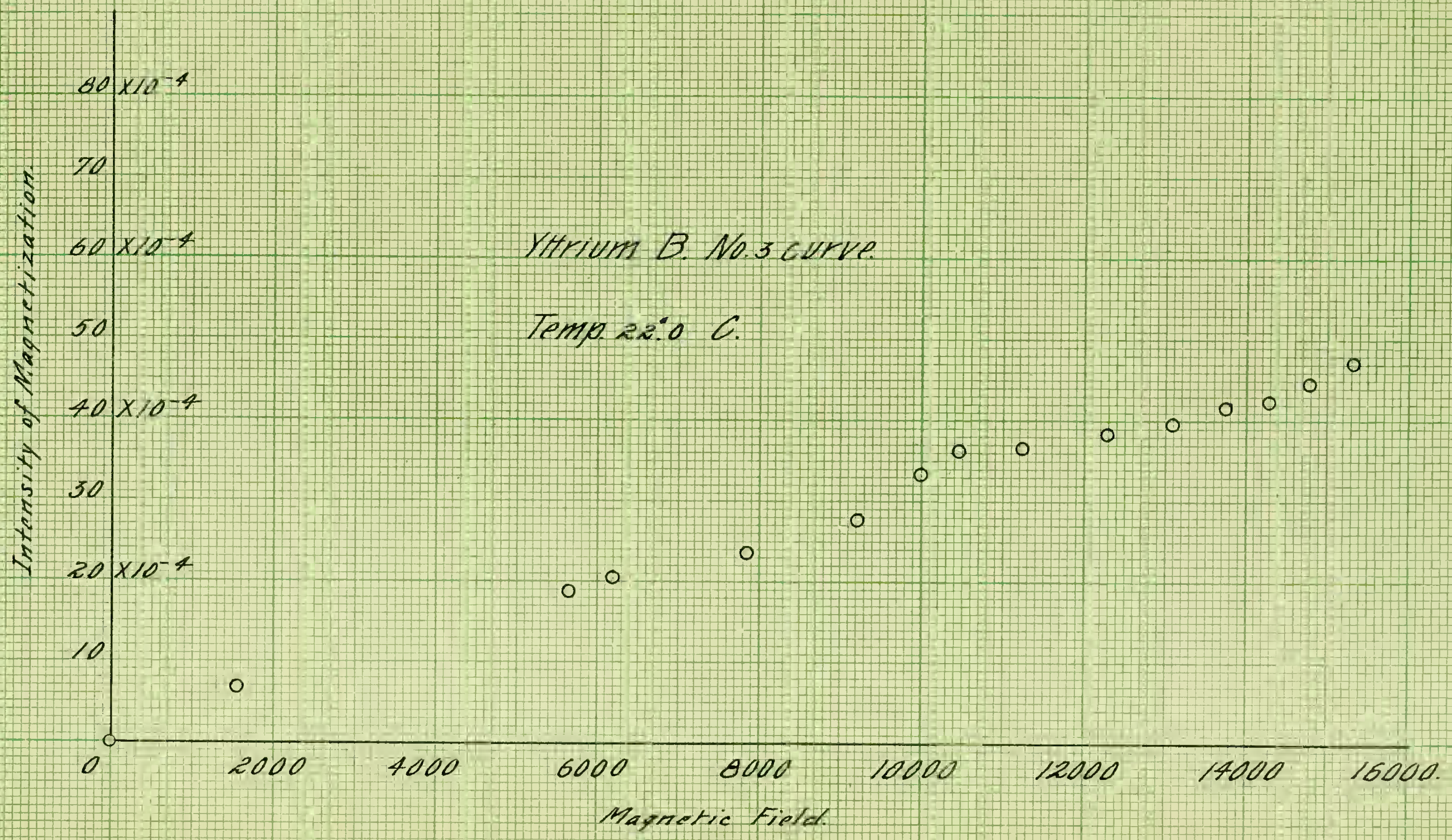


Yttrium A. No.4 curve.

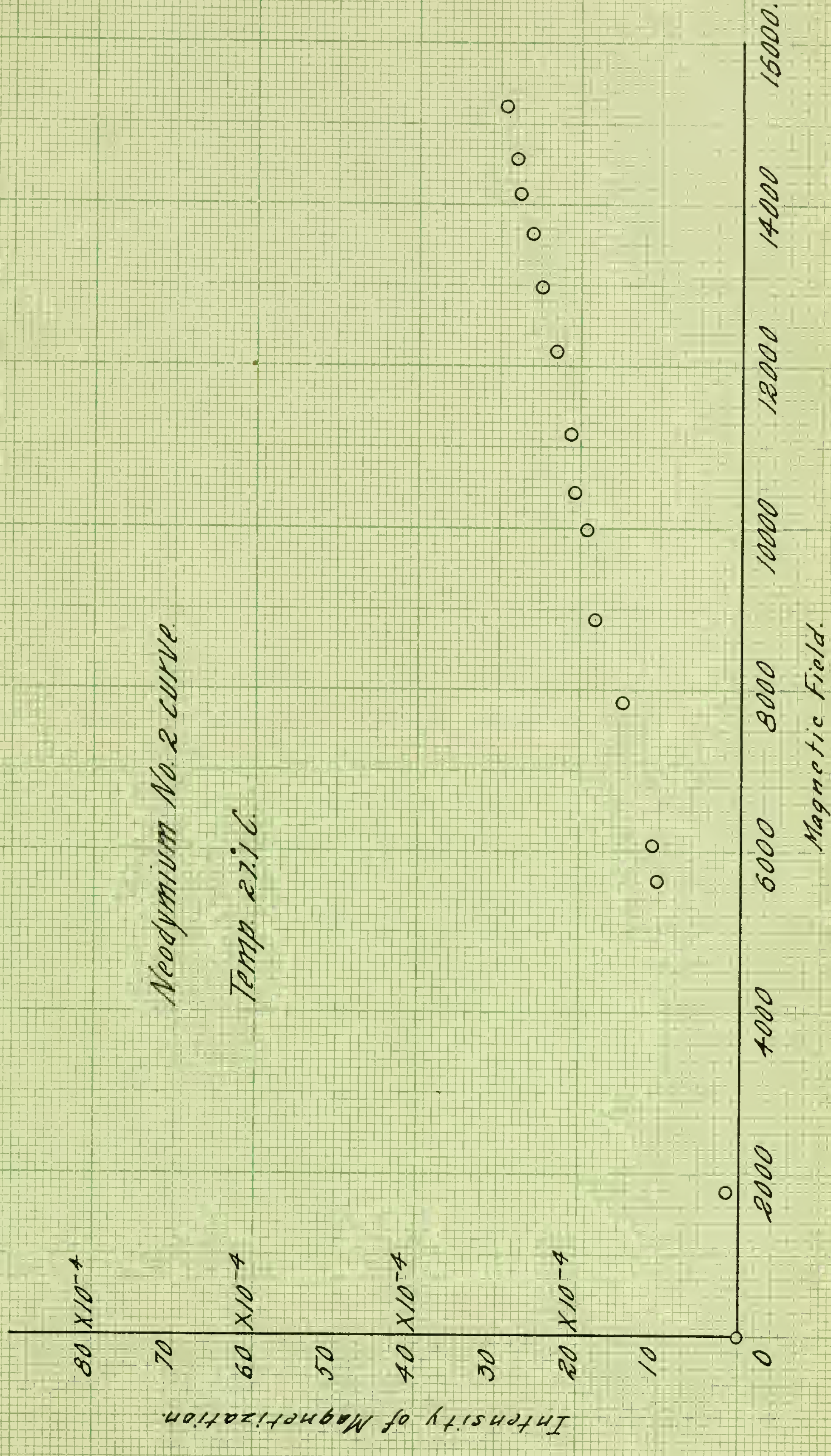
Temp. 21.0 C.

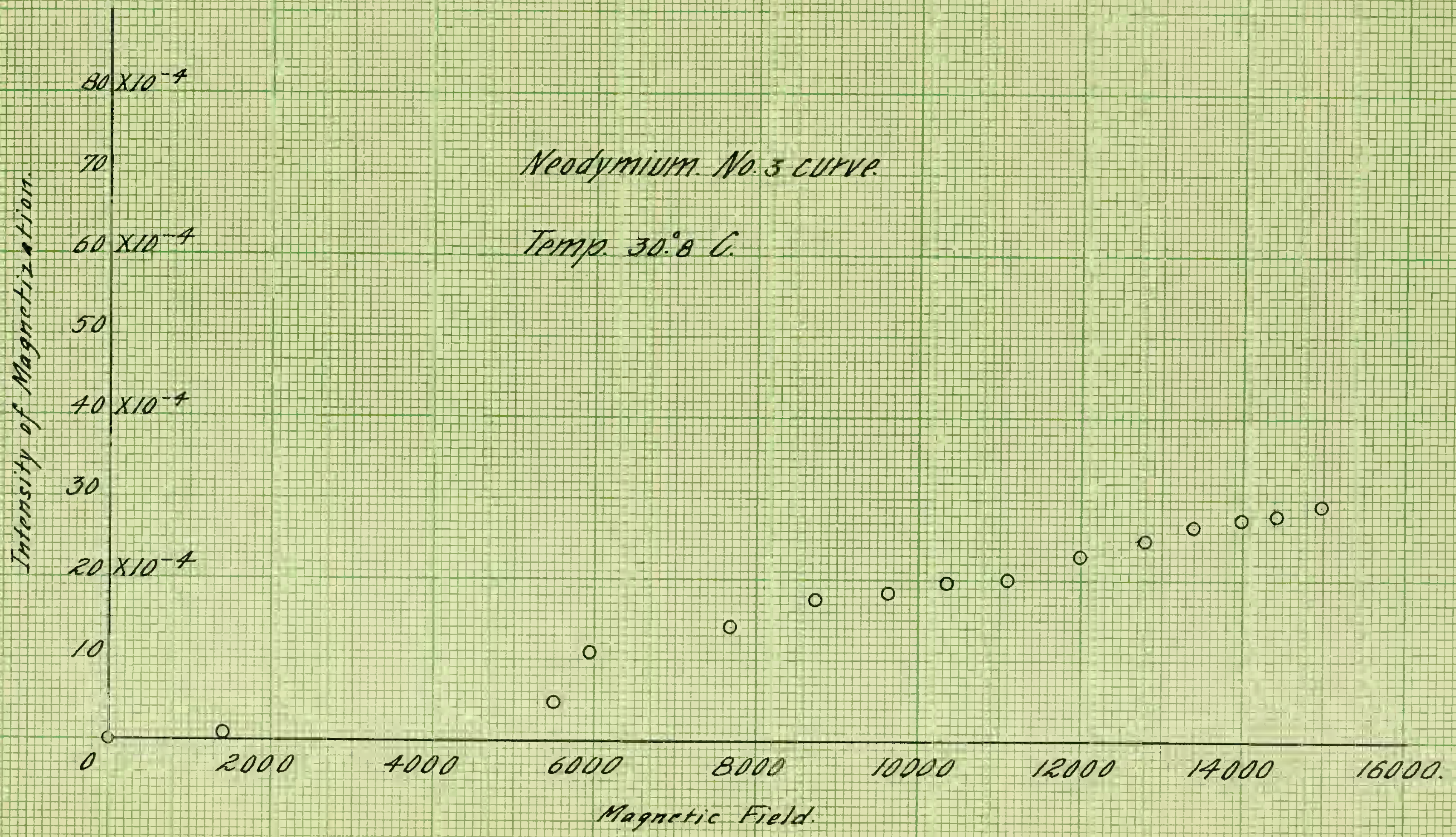

Yttrium B. No.1 curve
Temp. 22°.5 C
Magnetic Field.
Intensity of Magnetization.
80 X10-4
70
60 X10-4
50
40 X10-4
30
20 X10-4
10
0
2000
4000
6000
8000
10000
12000
14000
16000

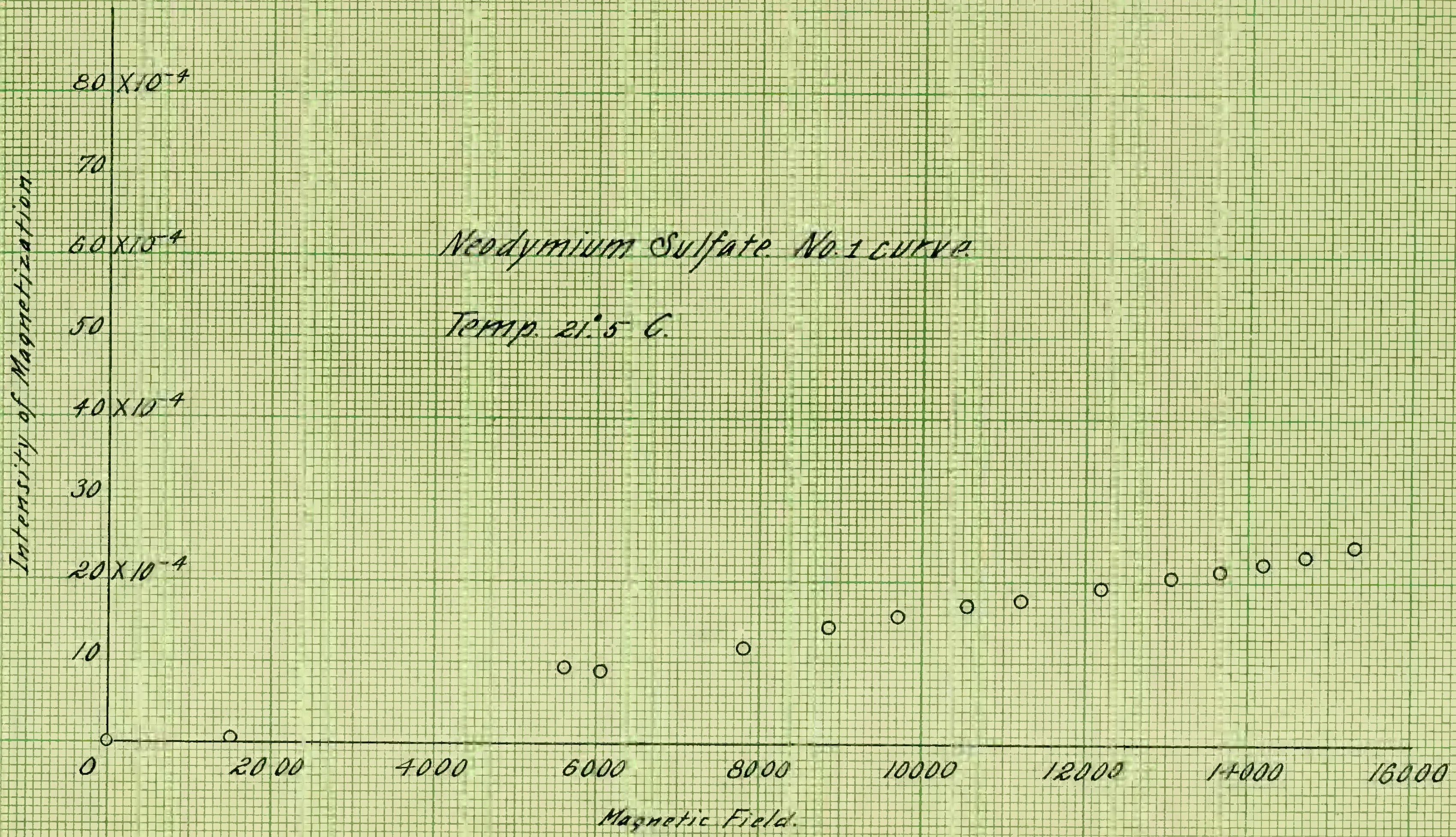

Yttrium B. No. 2 curve.
Temp. 23°.3 C.
Intensity of Magnetization.
80 X10⁻⁴
70
60 X10⁻⁴
50
40 X10⁻⁴
30
20 X10⁻⁴
10
0
2000
4000
6000
8000
10000
12000
14000
16000.
Magnetic Field.

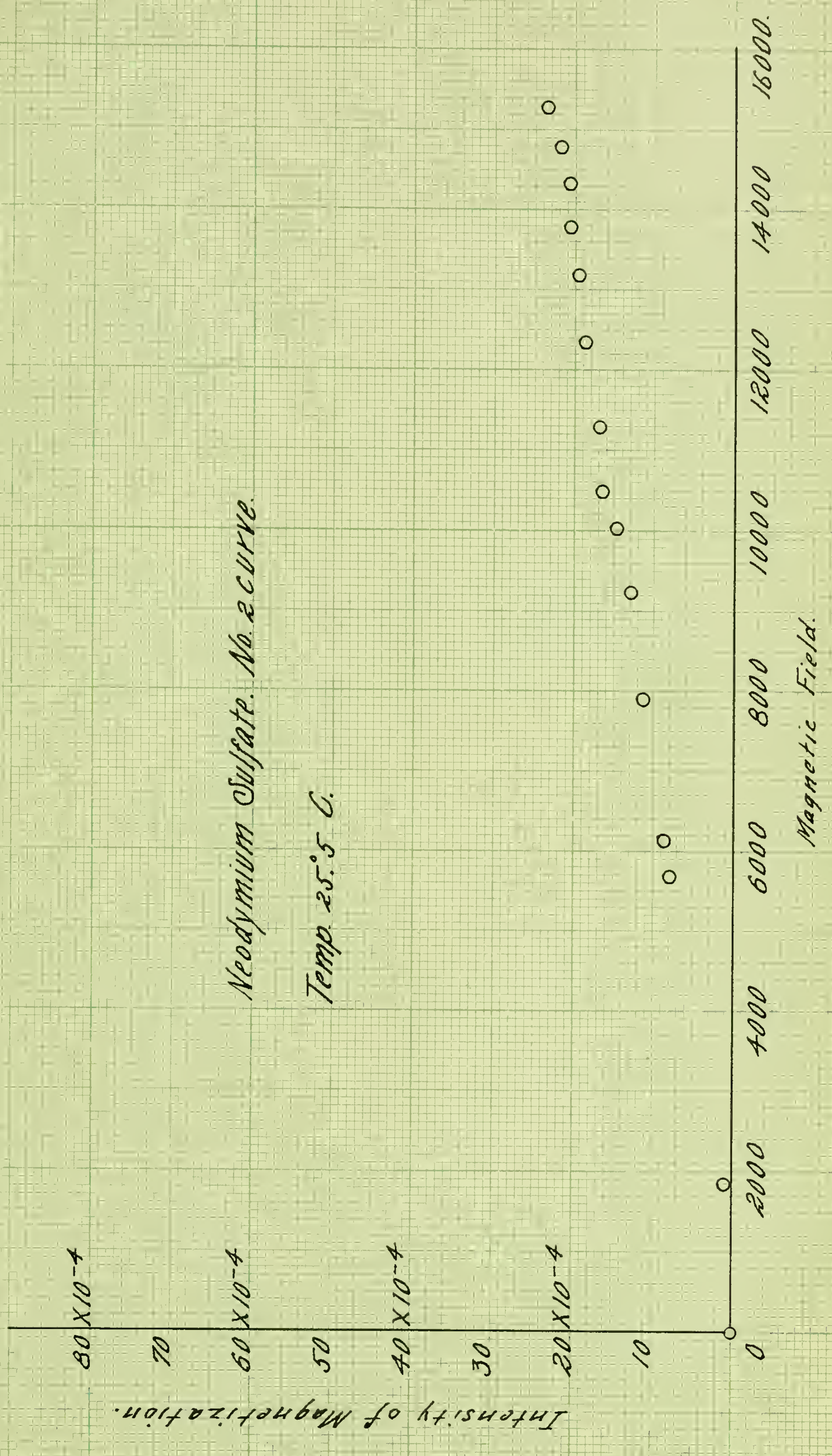

Yttrium B. No.3 curve.
Temp. 22°.0 C.
Intensity of Magnetization.
80 X10⁻⁴
70
60 X10⁻⁴
50
40 X10⁻⁴
30
20 X10⁻⁴
10
0
2000
4000
6000
8000
10000
12000
14000
16000.
Magnetic Field.


Neodymium No. 1 curve.
Temp. 24.0 C.
Intensity of Magnetization.
80 X10⁻⁴
70
60 X10⁻⁴
50
40 X10⁻⁴
30
20 X10⁻⁴
10
0
2000
4000
6000
8000
10000
12000
14000
16000
Magnetic Field.


Neodymium No. 2 curve
Temp. 27.1 C.
Intensity of Magnetization.
0
10
20 X10⁻⁴
30
40 X10⁻⁴
50
60 X10⁻⁴
70
80 X10⁻⁴
Magnetic Field.
2000
4000
6000
8000
10000
12000
14000
16000.

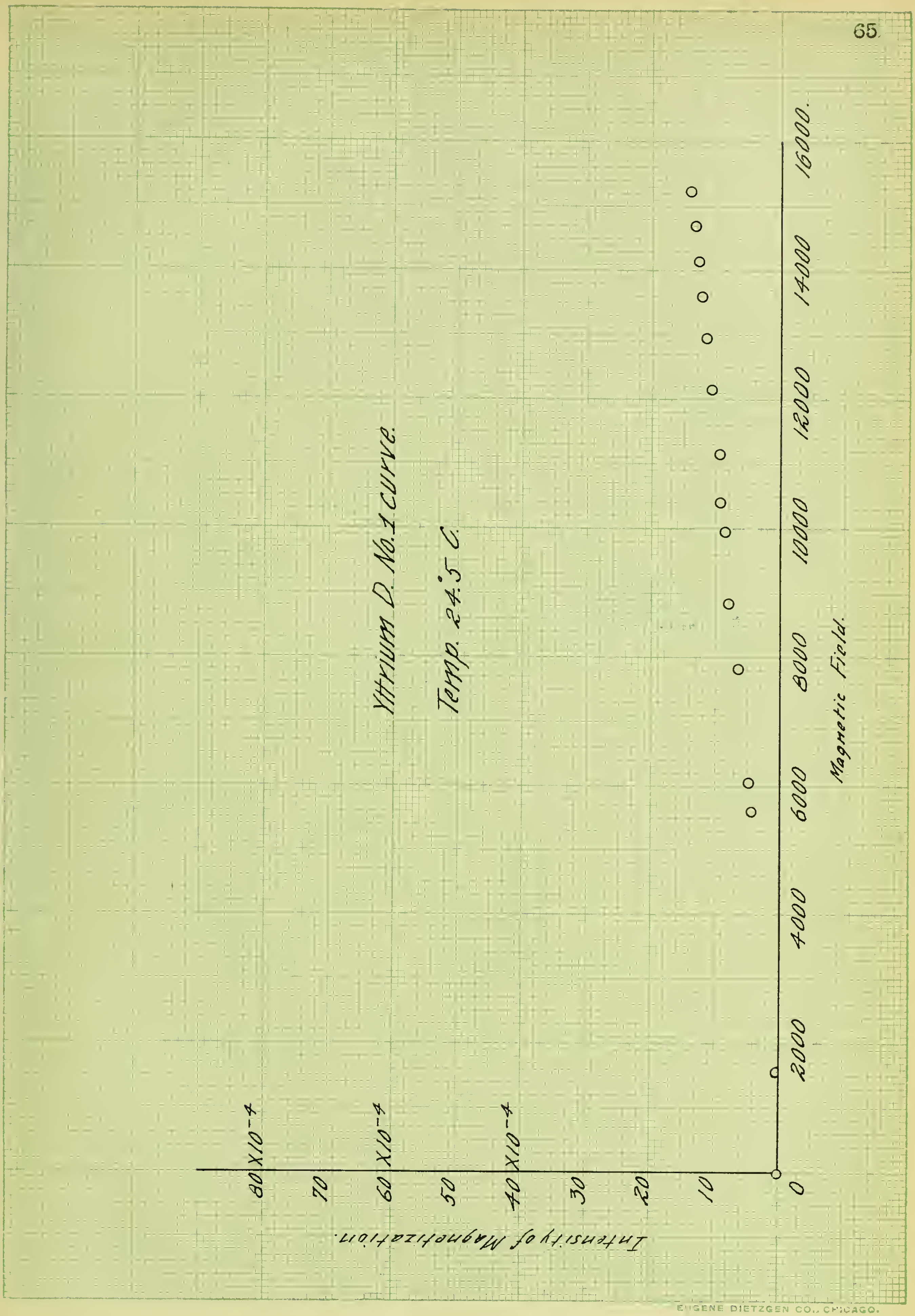

Neodymium. No. 3 curve.
Temp. 30°8 C.
Intensity of Magnetization.
80 X10⁻⁴
70
60 X10⁻⁴
50
40 X10⁻⁴
30
20 X10⁻⁴
10
0
2000
4000
6000
8000
10000
12000
14000
16000.
Magnetic Field.

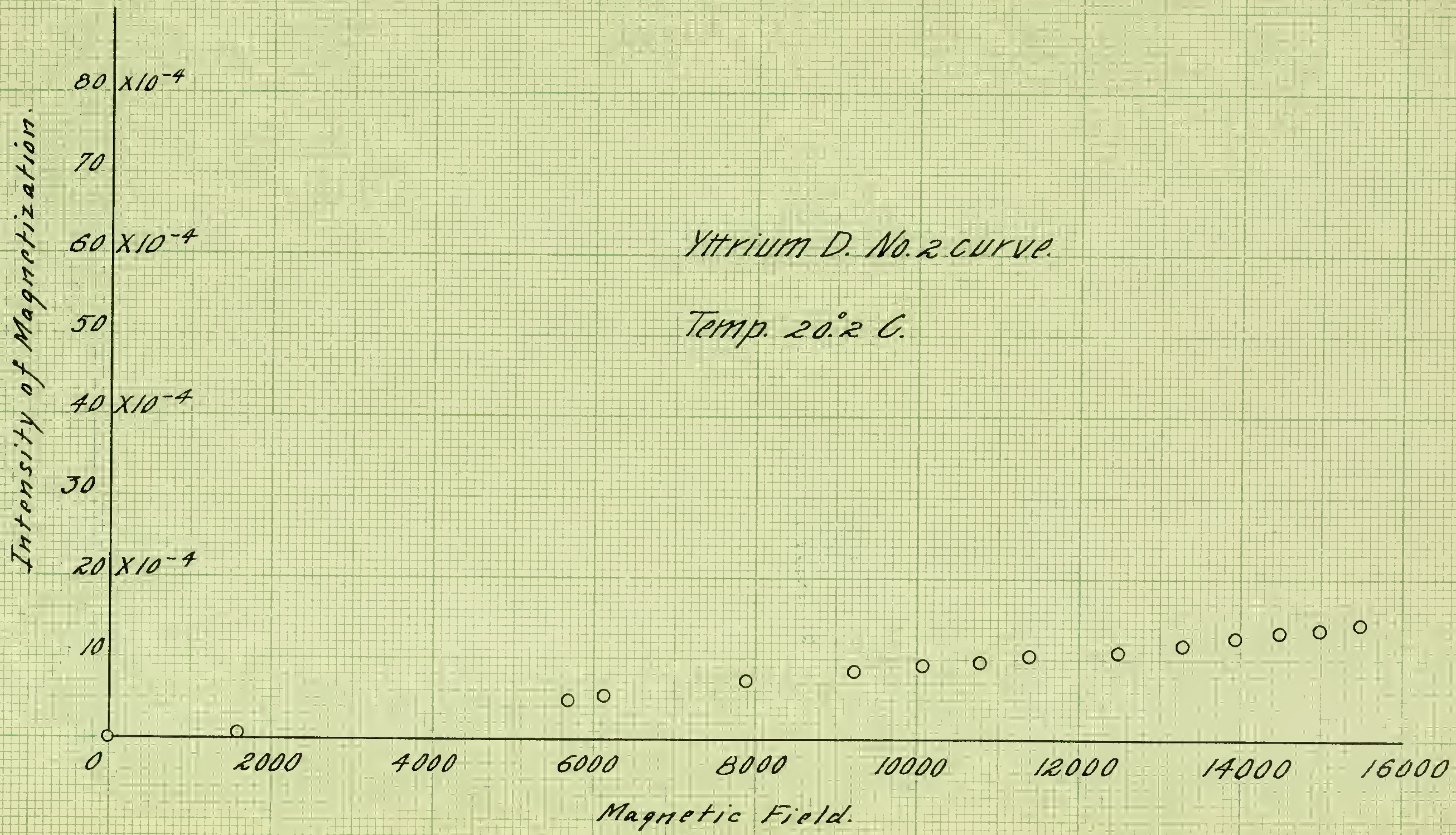

Neodymium Sulfate No. 1 curve
Temp. 21.5° C.
Intensity of Magnetization
80 X 10^-4
70
60 X 10^-4
50
40 X 10^-4
30
20 X 10^-4
10
0
2000
4000
6000
8000
10000
12000
14000
16000
Magnetic Field.

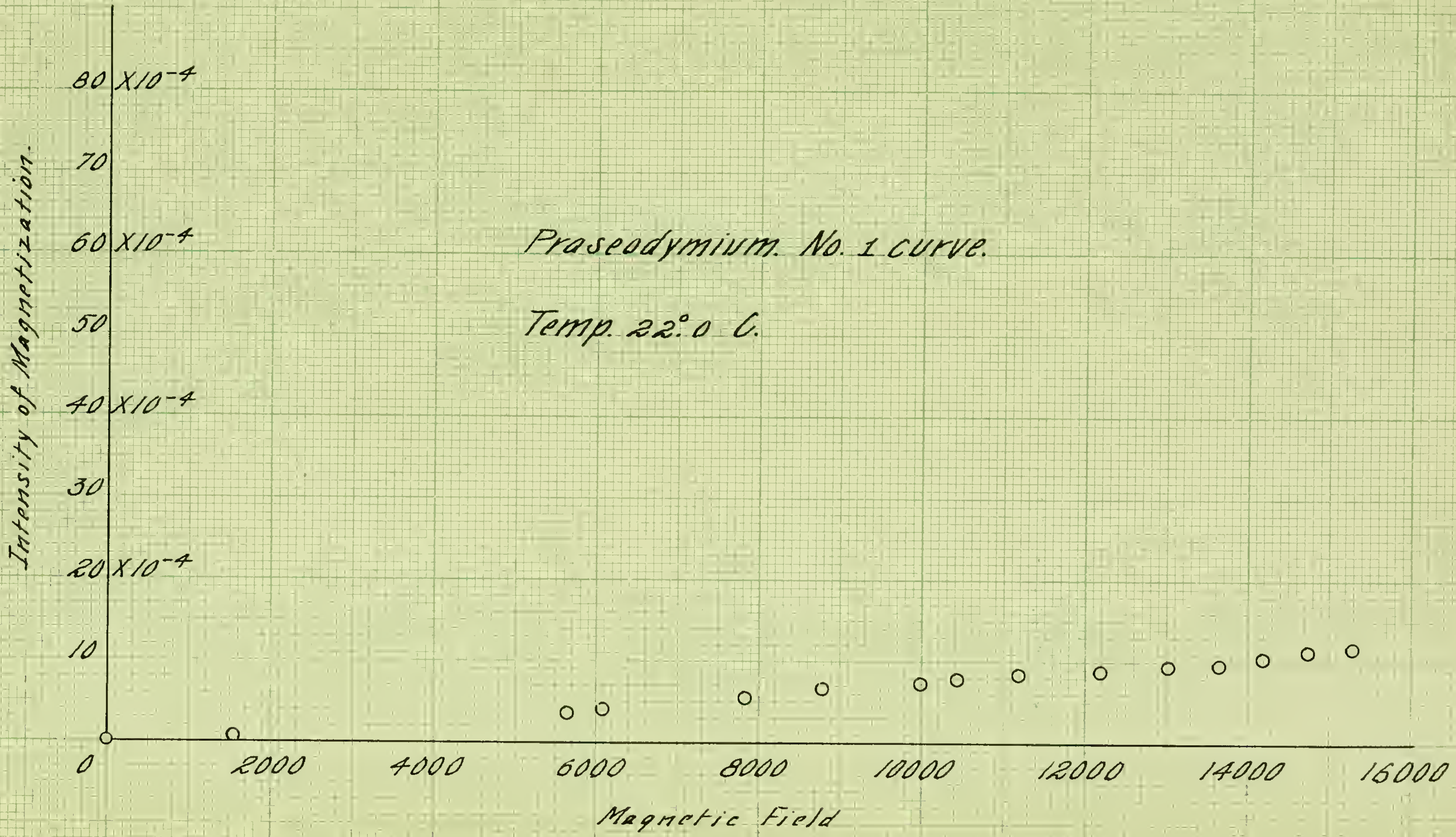


Neodymium Sulfate. No. 2 curve.

Temp 25.5 C.

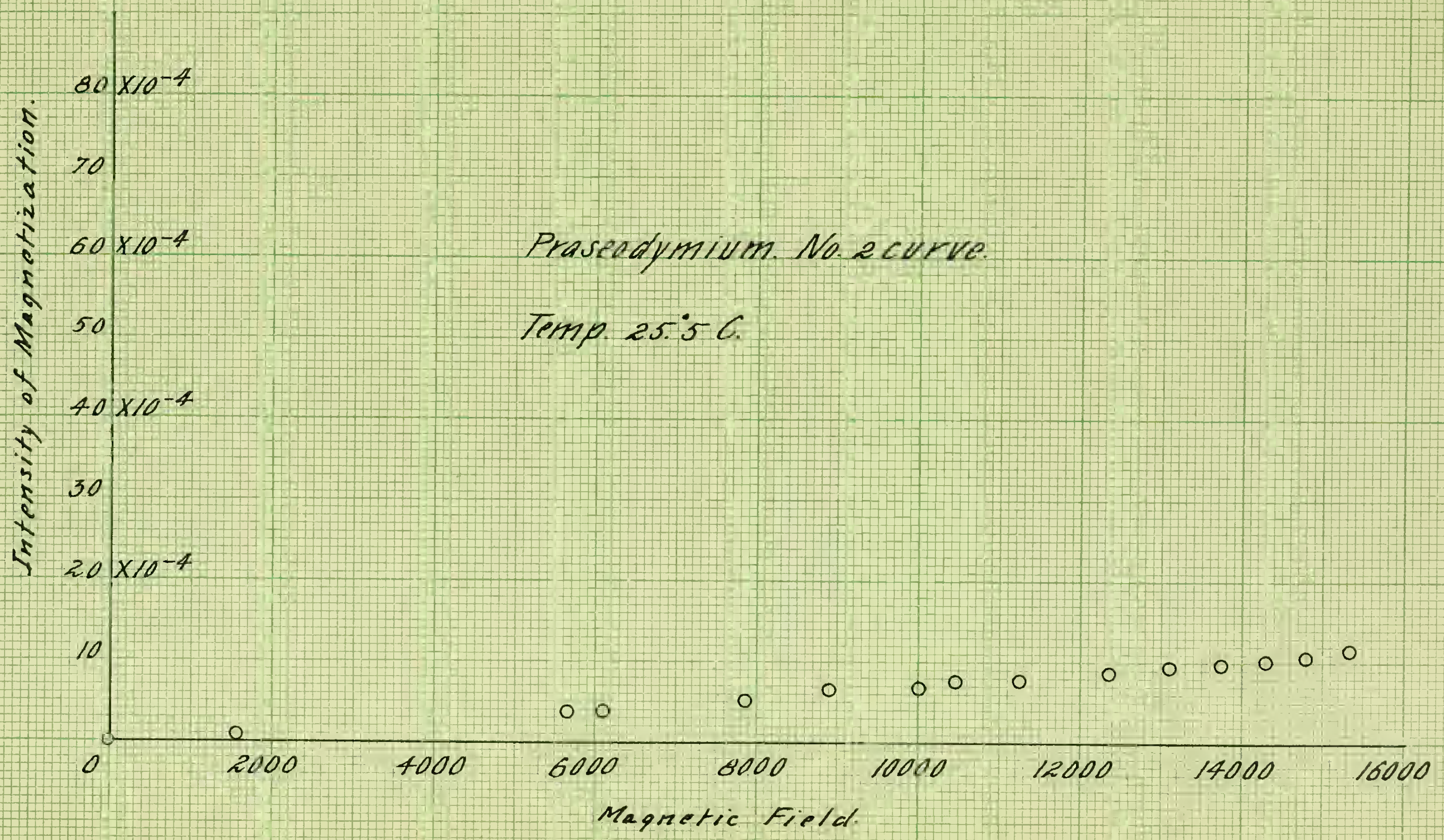

Yttrium D. No.1 curve.
Temp. 24.5° C.
Intensity of Magnetization.
80 X10^{-4}
70
60 X10^{-4}
50
40 X10^{-4}
30
20
10
0
2000
4000
6000
8000
10000
12000
14000
16000.
Magnetic Field.


Yttrium D. No. 2 curve.
Temp. 20°.2 C.
Intensity of Magnetization.
80 X10^-4
70
60 X10^-4
50
40 X10^-4
30
20 X10^-4
10
0
2000
4000
6000
8000
10000
12000
14000
16000
Magnetic Field.



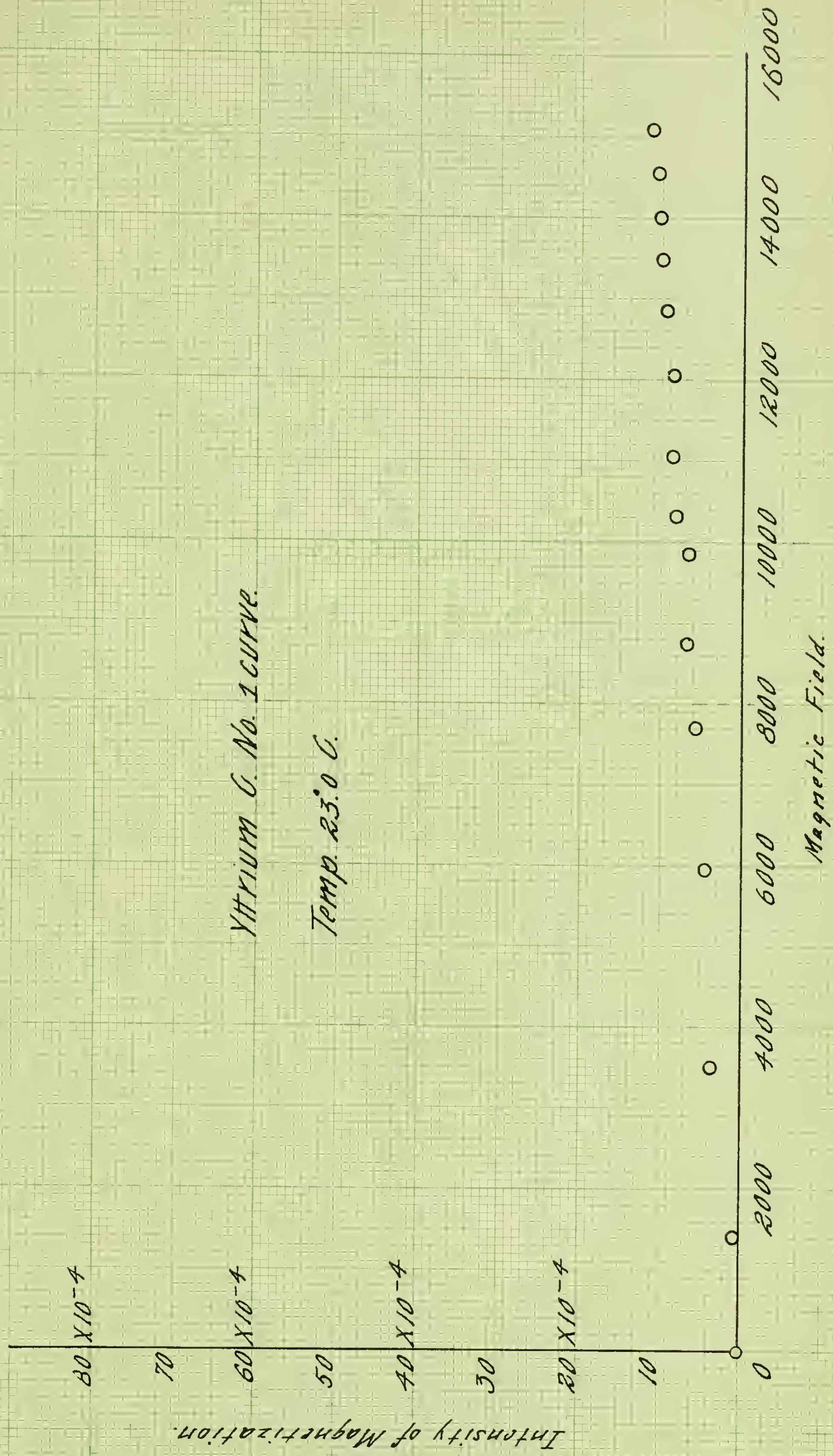
Praseodymium. No. 1 curve.

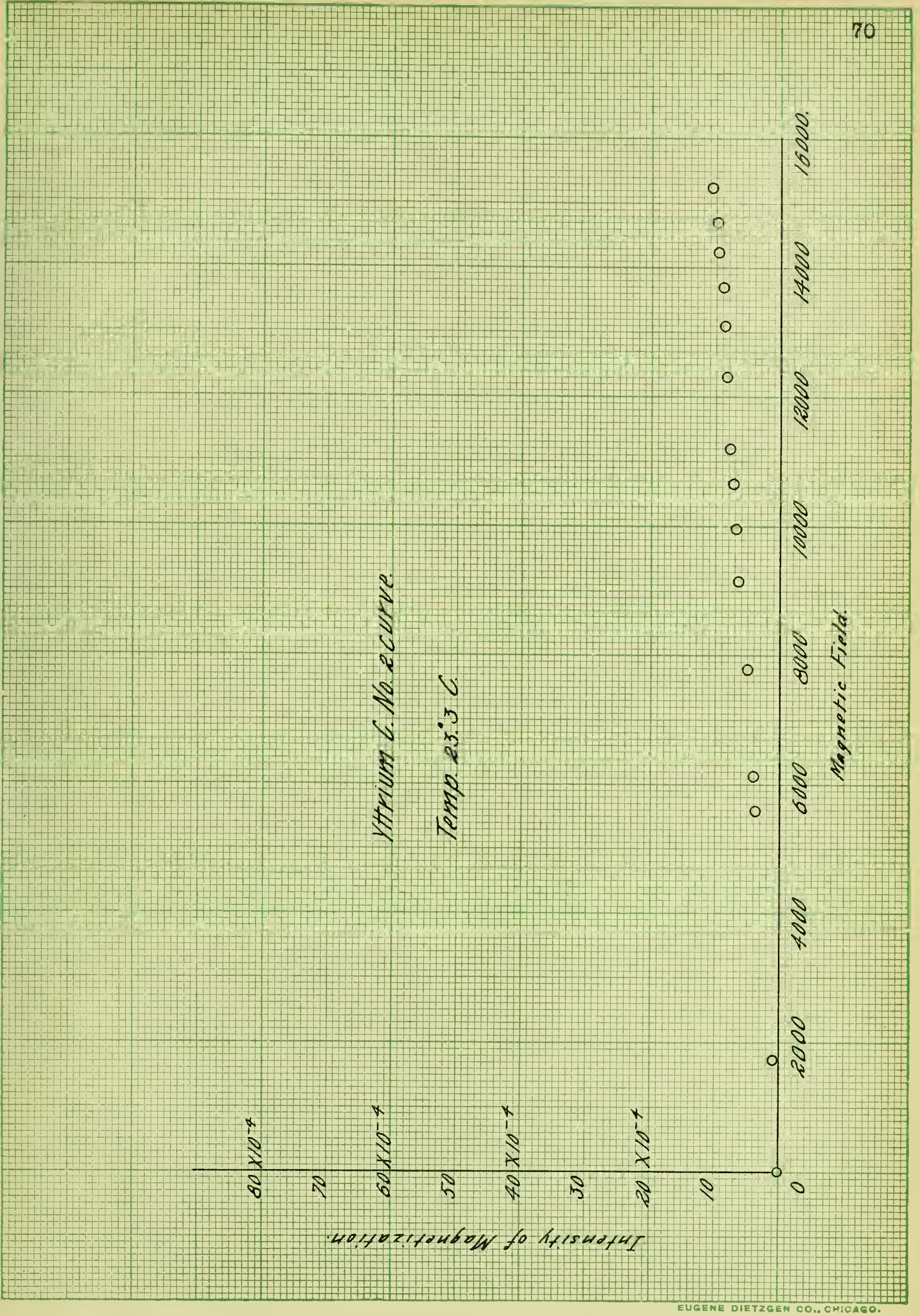
Temp. 22°0 C.

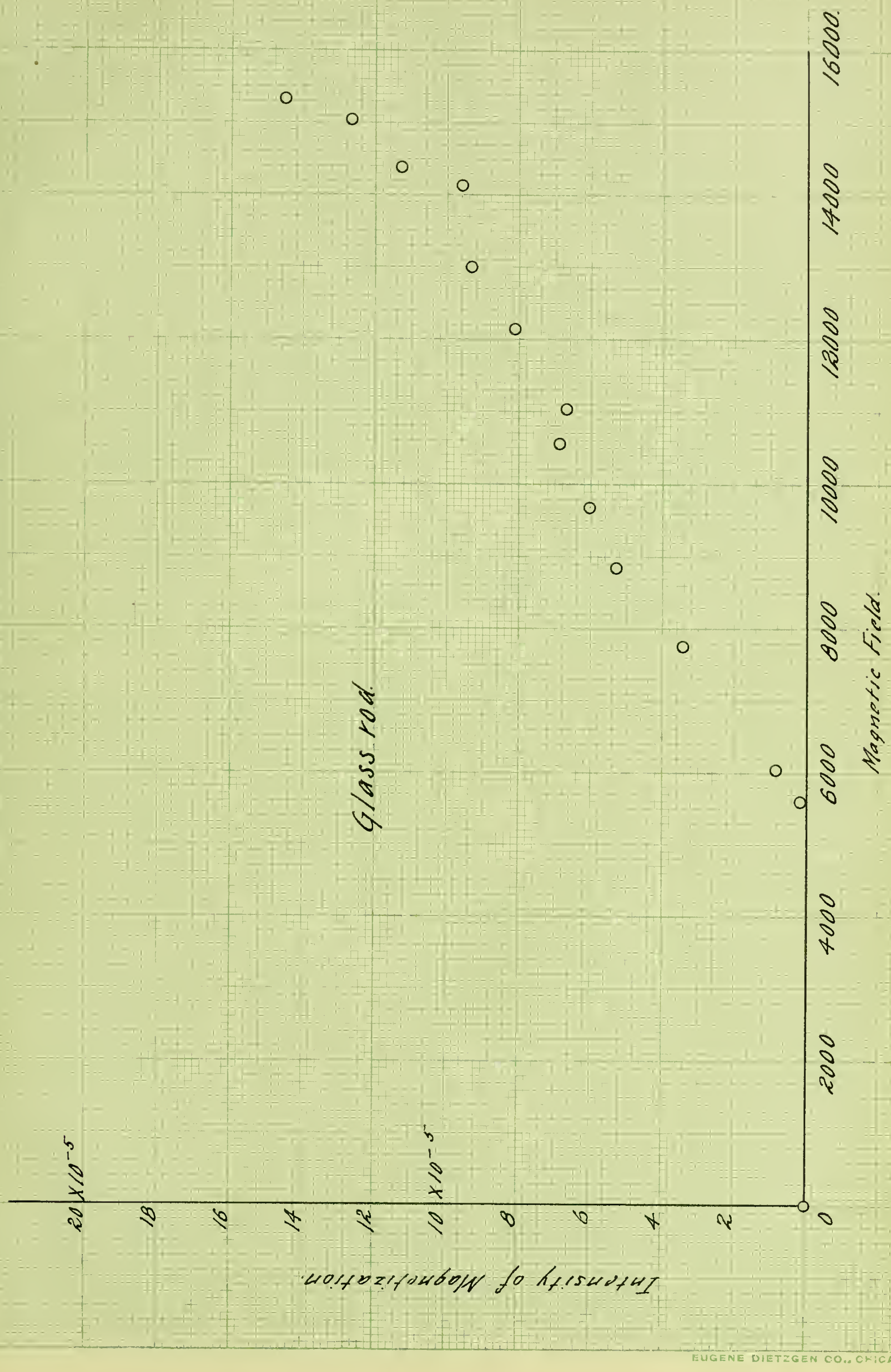


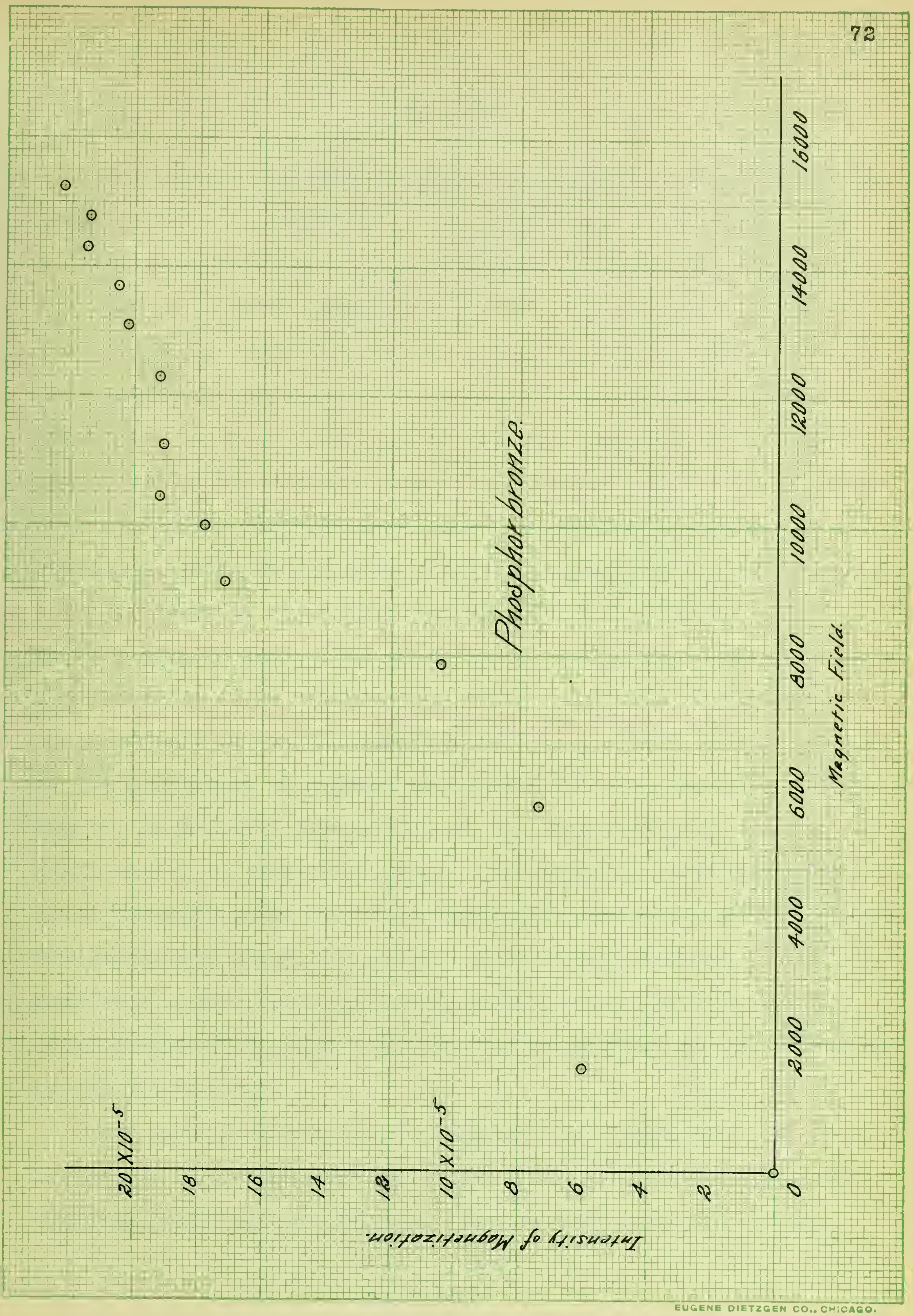
Praseodymium. No. 2 curve.

Temp. 25.°5 C.


Yttrium C. No. 1 curve.
Temp. 23.0 C.
Magnetic Field.
Intensity of Magnetization.
0
2000
4000
6000
8000
10000
12000
14000
16000
10
20 X10-4
30
40 X10-4
50
60 X10-4
70
80 X10-4


Yttrium C. No. 2 curve
Temp. 23°.3 C
Magnetic Field.
0
2000
4000
6000
8000
10000
12000
14000
16000.
Intensity of Magnetization.
10
20 X10⁻⁴
30
40 X10⁻⁴
50
60 X10⁻⁴
70
80 X10⁻⁴


Glass rod.
Intensity of Magnetization.
Magnetic Field.
20 X10⁻⁵
18
16
14
12
10 X10⁻⁵
8
6
4
2
0
2000
4000
6000
8000
10000
12000
14000
16000.


Phosphor bronze.
Magnetic Field.
0
2000
4000
6000
8000
10000
12000
14000
16000
Intensity of Magnetization.
0
2
4
6
8
10 X10-5
12
14
16
18
20 X10-5

Discussion.

The curves show that straight lines should be the true representations of the results and any deviations of the points from a straight line are due to inaccuracies which for any particular point may be additive.Some of these may be attributed to the fact that the whole suspended system could be pulled out from its true free position toward one or the other of the magnetic poles. This seems to be the case in the specimens showing the strongest magnetic properties while the weaker ones show that the deviations from a straight line are much less.This pulling of the whole suspended system to one side of its free position was decreased to a large extent by stretching two #36 B&S gauge phosphorbronze wires perpendicular to the direction of the field so as to have the suspension come between them close to the top of the glass strip and as near to the specimen as possible.This however,prevented the difficulty to a great extent but an error was introduced due to the friction between two of the phosphorbronze wires at right angles to each other,namely the suspension and one of the guide wires.It seems that this would give explanations for some of the deviations since the maximum torques measured were of the magnitude 0.0258 dyne-centimeter,and for the minimum 0.000002 dyne-centimeter.For the small torques no shifting of the suspended system was noticed.

But some of the points for the smaller values show larger deviations than those farther along in the increasing values of the field.This may be explained by the fact that some of the

specimens seemed to act very sluggishly in very weak fields and after a certain field strength the deflections were comparatively steady.That is,it seemed that very unstable polarity for some specimens is the result of the field not being strong enough;then after a strong enough field is obtained the polarity is more definite and steady.This showed up very distinctly in some of the observations on specimens in weak fields of about 1600 to 5000 in that their behavior was very erratic.

Errors are introduced due to the suspension system being made of glass and phosphorbronze.The various field strengths used were applied without a specimen in the suspended system but no appreciable deflections could be detected except for extreme values of field.For this reason it was thought worth while to take a set of readings of glass and phosphorbronze.From the values obtained it is seen that even the extreme values are negligible in comparison with those of the rare earths.Although glass and the constituents are diamagnetic the specimens show definite paramagnetism which is due to iron or other magnetic substances in them.

Errors would be introduced in getting the area of cross section of the specimens but since this would be a constant it would cause no erratic deviations from the curves.

In the table of maximum values for H and A it is seen that the Erbium specimen shows the largest values for A,Terbium is second, Yttrium A and B third and fourth respectively,with Praseodymium seventh,and Yttrium C specimen last the weakest of them all.This variation is explained later.

Table of Maximum Values.

Names of Specimen	No.	Temp.°C.	H	A X 10^4
Erbium oxide	1	22.5	15250	77.5
" "	2	26.8	15300	72.4
" "	3	28.5	15200	71.3
" "	4	33.0	15200	65.1
Terbium "	1	25.0	15250	72.3
" "	2	22.0	15250	73.7
Yttrium A "	1	24.0	15250	53.0
" "	2	22.5	15400	68.3
" "	3	21.8	15350	53.5
2	4	21.0	15350	40.8
Yttrium B "	1	22.5	15250	48.7
" "	2	23.3	15450	50.2
" "	3	22.0	15350	47.0
Neodymium oxide	1	24.0	15250	27.9
" "	2	27.1	15250	29.1
" "	3	30.8	15150	29.1
Neodymium sulfate	1	21.5	15350	24.4
" "	2	25.5	15250	23.1
Yttrium oxide D	1	24.5	15300	13.8
" "	2	20.2	15450	14.0
Praseodymium oxide	1	22.0	15300	11.7
" "	2	25.5	15350	11.1
Yttrium oxide C	1	23.0	15250	10.0
" "	2	23.3	15300	10.2

The method of getting the rare earths is by means of fractional crystallizations,and any one crystallization may leave the remaining solution with two or more of the other rare earths which do not crystallize out.The only way to detect whether or not other earths are present in the solution besides the one desired,is by spectroscopic analysis.Some of the rare earths have absorption spectra and others do not, so that it is necessary to analyse them by means of their emission spectra.This method of separating and determining the presence of other than the desired elements is a long,laborious task since it requires thousands of these fractional crystallizations.

The order in which the rare earths are produced by fractional crystallizations is the following:-

Lanthanum,Praseodymium,Neodymium,Samarium,Europium,Gadolinium, Terbium,Dysprosium,Holmium,Yttrium,Erbium,Thulium,Ytterbium,and Scandium.

It is seen that Yttrium lies between Holmium and Erbium in this grouping and shows that if an Yttrium specimen is not pure, the impurity is most likely to be Erbium or Holmium.Since Erbium shows the strongest magnetic properties it seems that the strong magnetic intensities shown by Yttrium specimens A and B are due to the presence of Erbium and other rare earths.The color of these specimens was not white as they should be for the pure Yttrium. Specimens C and D show very weak magnetic properties because they contain very little if any,of the Erbium or other rare earths. This is also shown by their color which was almost a pure white. This shows that pure Yttrium is much less magnetic than Erbium and agrees with the conclusions of B. Urbain and G. Jantsch.

Neodymium oxide and sulfate occur next in order of intensity below Yttrium A and B,while Praseodymium oxide is farther down in the table of maximum intensities.This is in harmony with the grouping as shown above , in which Neodymium comes after Praseodymium and nearer to Erbium,and is more likely to have the larger amount of Erbium if they are not pure.It is however possible that they are in their proper order of intensities of magnetization on account of their own inherent magnetic properties.

The Terbium specimen seems to be contradictory to this explanation since it lies farther from Erbium thandoes Yttrium in the grouping.Nothing definite can be said about the Terbium specimen for it is known to contain a large proportion of Erbium.It seems very probable that it contains all of the following rare earths Dysprosium,Holmium,Yttrium,and Erbium.

From the table of maximum values it is seen that there is some variation with the temperature.Since the temperature changes of most of the specimens were not more that 4° or 5° C,no definite conclusions can be formed.On account of the extreme difficulty in getting large temperature changes and,at the same time ~~be able~~ to measure them accurately without causing large errors in the magnetic measurements,it was decided not to attempt it in this investigation.

Erbium shows a little decrease of magnetic intensity with increase of temperature but even these variations are not consistent The temperature change in this case was about 10°C.It shows however,that temperature affectsthe magnetic properties to some extent.The temperatures were read from a 0° - 100°C mercury - in - glass thermometer hung far enough above the field to avoid errors which the magnetic field would cause.For this reason the actual

temperature of the specimens might have been somewhat higher than the thermometer readings.

Conclusions.

This investigation shows that the variation of the intensity of magnetization with the strength of magnetic field is a straight line function for the specimen tested.

The intensity of magnetization of Erbium oxide shows about 7.5 times that of the purest specimen of Yttrium oxide,which is the weakest of them all.

The intensity of magnetization curves for all the rare earths used in this investigation are straight lines and show a tendency of a variation in their slopes to correspond with the arrangement given in the table by B. Urbain and G.Jantsch.

The intensity of magnetization is sensitive to temperature changes.

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